Idaho National Engineering and Environmental Laboratory

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September 2000

Post–Record of Decision Monitoring Report from 1996-1998 at Operable Unit 4-12, Central Facilities Area Landfills I, II, and III (CFA-01, CFA-02, and CFA-03)

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Idaho National Engineering and Environmental Laboratory
Environmental Restoration Directorate
Idaho Falls, Idaho 83415

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Approved by

Harry D. Williams WAG 4 Project Manager	Date

ABSTRACT

The Post-Record of Decision monitoring report for Operable Unit 4-12 describes the monitoring activities conducted and presents the groundwater and vadose zone monitoring results for the Central Facilities Area Landfills I, II, and III. Groundwater monitoring included sampling for major anions and cations, metal and volatile organic compounds. Groundwater levels were monitored to determine groundwater flow directions and potential pathways of contaminant migration. The vadose zone monitoring included infiltration measurements and soil gas sampling. Infiltration measurements were used to evaluate the cover performance. Groundwater and vadose zone gas sampling were used to establish baseline contaminant levels.

The groundwater monitoring results indicate that the landfills are not impacting the groundwater. Groundwater levels indicate a south to southwest regional groundwater flow direction. The soil gas sampling results indicate that some volatile organic compound vapors have migrated below the landfills, but have not impacted the groundwater. Recommendations are provided to improve the monitoring system. The monitoring data are included in the appendices.

EXECUTIVE SUMMARY

The Post-Record of Decision monitoring at Operable Unit 4-12 was prepared to support the Federal Facility Agreement and Consent Order for the U.S. Department of Energy Idaho Operations Office at the Idaho National Engineering and Environmental Laboratory. The objectives of this report are described below.

The Operable Unit 4-12 Record of Decision documented that the risk associated with the Central Facilities Area (CFA) landfills was found to be within the generally accepted limits of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) (i.e., the risk assessment indicated that the landfills posed no unacceptable threat to human health and environment).

Due to the uncertainty about the waste disposal history, a remedial action of containment consisting of native soil covers was warranted for the site, consistent with U.S. Environmental Protection Agency presumptive remedy guidance for CERCLA municipal landfills. The monitoring work plan specified that an agency review of monitoring data would take place at the end of the short-term (2-year) intensive monitoring phase.

Objectives

The objectives of the Post-Record of Decision monitoring include:

1. Monitor infiltration of moisture through the landfill covers

2. Monitor soil-gas volatile organic compounds and methane concentrations in the vadose zone near each landfill

3. Monitor concentrations of volatile organic compounds, metal and anions/cations in the groundwater in the vicinity of the landfills

4. Establish a baseline of chemical concentrations in the aquifer against which future data can be compared

5. Monitor groundwater flow direction in the aquifer in the vicinity of the landfills.

Summary of Monitoring Results and Interpretation

Infiltration Monitoring—Cover Effectiveness

Neutron probe and time domain reflectometer data were used to estimate infiltration and recharge. Neutron probe data suggest that recharge is probably sporadic and depends not only on the amount of precipitation that falls in the winter, but also on the accumulation of snow and the suddenness of the snow melt. Estimates of recharge in 1998 ranged from 0.28 cm (0.11 in.) for LF3-05 to 6.53 cm (2.57 in.) for LF2-04. Recharge in 1998 was estimated using a water balance method and using calibration equations, but both methods yielded similar results. In contrast, recharge in 1997 was much less and ranged from not detectable to 2.0 cm (0.81 in.) at LF3-03. Evaluation of the change of water in storage in the soil below the landfills suggests that the covers are reducing the amount of infiltration.

Setting an action level based on impact to groundwater requires making assumptions as to the source size, concentration, compounds that might be present, and the amount of time that a source may have been leaking. Because of the high degree of uncertainity associated with making the above assumptions, establishing an action level for infiltration through the covers based on impact to groundwater would be very problematic. The viability of setting an action level for moisture infiltration will be re-assessed following the collection and interpretation of additional data through 2003.

Soil Gas Monitoring

Soil gases were collected and analyzed at four discrete depths from approximately 3.3 m (11 ft) to approximately 31.6 m (104 ft) below land surface at five locations adjacent to the landfills. Although the VOC data are variable and no clear trends are apparent, the following observations can be made. Of the 18 VOCs evaluated in the gas sampling, the following seven VOCs were reported most frequently and at the highest levels: 1,1,1-trichloroethane, 1,1-dichloroethane, 1,1-dichloroethene, methane, trichloroethene, dichlorodifluoromethane and trichlorofluoromethane. 1,1-Dichloroethane and 1,1-dichloroethene are most likely degradation products of 1,1,1-trichloroethane and methane is a common product of the anaerobic degradation of landfill wastes.

Boreholes GSP 3-1, GSP 1-1 and GSP 2-1 reported the highest concentrations of gas-phase VOCs, while GSP 3-2 and GSP 2-1 showed the lowest levels. The highest gas-phase VOC concentrations in the individual boreholes were detected with essentially equal frequency at the two intermediate sampling ports approximately 12.2 m (40 ft) and 21.3 m (70 ft) below grade. With only a few exceptions, concentrations decreased at the lowest sampling depth for all VOCs in all five boreholes.

The soil gas ports are installed adjacent to known fracture zones in the basalt. The organic vapors are probably migrating through preferential vertical and horizontal flow paths in the fractured basalt. Based on levels of VOCs in the vadose zone at RWMC and the resultant impact on groundwater, it is unlikely that the observed concentrations at the CFA landfills pose a risk to the underlying aquifer.

Groundwater Analytical Results

No organic constituents in the CFA monitoring network exceed the MCLs for organic compounds. Mercury and cadmium were reported at concentrations slightly above their MCLs in single samples from different wells. Lead concentrations are elevated in one well; nitrate concentrations are elevated in two wells.

The average lead concentration in CFA-MON-003 during 1996–1998 was 21.8 μg/L, which is above the State of Idaho groundwater standard of 15 μg/L. However, the concentrations are decreasing and the source of the lead appears to be a localized phenomenon. Background lead levels in and around the INEEL range between 1 and 5 μg/L.

Nitrate concentrations average 17 mg-N/L in CFA-MON-002 and 9.4 mg-N/L in CFA-MON-003. Trend analysis indicates that nitrate concentrations are gradually declining in CFA-MON-002 and are remaining steady in CFA-MON-003. The MCL for nitrate is 10 mg-N/L. Background nitrate concentrations range between 1 and 2 mg-N/L; upgradient nitrate levels at INTEC are between 1 and 5 mg-N/L. The source of the nitrate will be further evaluated in an Engineering Design File.

Groundwater Flow—Water-level Monitoring

The water level contour maps in the vicinity of the CFA reveal a groundwater direction that is mainly south to southwest. Measured gradients of hydraulic head in the direction of flow range from less than 0.2 m/km (1 ft/mi) to more than 1.5 m/km (8 ft/mi). Because of measurement uncertainties, the contour map's accuracy is reduced to more of a regional-scale characterization of gradients and groundwater flow direction.

It is important to note that a chloride isoconcentration map generated for this report also shows a south-southwest groundwater flow direction in the vicinity of the landfills. Additionally, maps from the State of Idaho, INEEL Oversight Program for chloride show the same south-southwest flow direction around the landfills over the past 30 years.

Recommendations

The following recommendations are made to improve the monitoring plan:

Cover Infiltration Monitoring

- The HELP model should not be used to evaluate infiltration or recharge rates for the landfills because this model is not applicable to arid regions. UNSAT-H is a model that can be used to determine infiltration and recharge rates in arid climate settings.

- Increase the frequency of NAT monitoring in late winter and early spring. The suggested schedule of NAT monitoring is: twice a month in January, February, March and April, and once a month during the rest of the year. The frequency of monitoring should be increased during periods of higher precipitation.

- Measure the total depth and casing stick-up of the NATs. This will improve the accuracy of the depths assigned to the neutron probe stops.

- Install vertical TDR probes to a depth of 2.4 m (8 ft) in Landfills II and III. Monitoring data should be compared to NAT infiltration calculations to determine if this method gives the same infiltration rate estimates as the neutron probe measurements at depth.

Soil Gas Monitoring

- Sampling of soil gas should continue twice a year through 2003 so that more data can be evaluated.

- Following the collection of additional soil gas data, modeling of potential soil gas impacts on groundwater should be conducted to determined if detected contaminants pose a risk to groundwater.

- The work plan states that an action level for VOCs in the vadoze zone would be established in this report. However, as has been discussed with the agencies, it is unclear that a meaningful action level for vadose zone vapors can be established. This decision will be deferred until additional soil gas data are collected.

Water Level Monitoring

- Water-level data will be collected on a monthly basis for 1 year with a steel tape.

- The following wells should be resurveyed with gyroscopic deviation equipment at a downhole interval of 7.6 m (25 ft): USGS-20, USGS-111, USGS-116, CFA-MON-A-001, CFA-MON-A-002, and CFA-MON-A-003. Information from the resurveyed wells should be used to redevelop the correction formula used to obtain true water levels in these highly deviated wells.

Groundwater Sampling

- Groundwater sampling should continue on a schedule of no less than every 12 months. Analytes should be expanded to include tritium.

- LF 2-10, LF 2-08, and LF 3-09 should be removed from the list of wells being monitored.

- USGS-85 should not be designated as the upgradient well for Landfills I and III. USGS-112 would serve better as the upgradient well for Landfills I and III.

- USGS-83 should be added to the list of wells to be sampled to evaluate the downgradient concentration of nitrate. The pump should be raised to near the water table prior to sampling.

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ACRONYMS

ANL-W	Argonne National Laboratory-West
BGS	below ground surface
bls	below land surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFA	Central Facilities Area
CLP	Contract Laboratory Program
COC	contaminant of concern
CPN	Campbell Pacific Nuclear Corporation
DOE	Department of Energy
DOE-ID	U.S. Department of Energy Idaho Operations Office
EBTF	Engineered Barrier Test Facility
EDF	Engineering Design File
EPA	U.S. Environmental Protection Agency
ET	Evapotranspiration
FFA/CO	Federal Facility Agreement and Compliance Order
FR	federal register
GSP	gas sampling port
HELP	Hydrologic Evaluation of Landfill Performance
IDHW	State of Idaho Department of Health and Welfare
INEEL	Idaho National Engineering and Environmental Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
LMITCO	Lockheed Martin Idaho Technologies Company
MCL	maximum contaminant level

NAT	neutron access tube
NOAA	National Ocean and Atmospheric Administration
NPL	National Priorities List
NPF	Naval Reactors Facility
OU	Operable Unit
PRG	preliminary remediation goals
QC	quality control
RAOs	remedial action objective
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision
RPD	relative percent difference
RWMC	Radioactive Waste Management Complex
SDA	Subsurface Disposal Area
SMCL	secondary maximum contaminant level
SRPA	Snake River Plain Aquifer
TAN	Test Area North
TDR	time domain reflectometer
TRA	Test Reactor Area
USGS	U.S. Geological Survey
VOC	volatile organic compound
WAG	waste area group

Post–Record of Decision Monitoring Report at Operable Unit 4-12, Central Facilities Area Landfills I, II, and III (CFA-01, CFA-02, and CFA-03)

1. INTRODUCTION

On October 10, 1995, the U.S. Environmental Protection Agency (EPA) Region 10, the State of Idaho Department of Health and Welfare (IDHW), and the U.S. Department of Energy Idaho Operations Office (DOE-ID) signed the Record of Decision (ROD) for the Central Facilities Area (CFA) Landfills I, II, and III (Operable Unit [OU] 4-12) at the Idaho National Engineering and Environmental Laboratory (INEEL) in southeastern Idaho, which required installation of native covers. The ROD required monitoring of groundwater and the vadose zone overlying the Snake River Plain Aquifer (SRPA) at all three landfills, and monitoring of water infiltration into the soil covers placed over the landfills. This report describes the results of the monitoring conducted from October 1996 to September 1998.

The infiltration, soil gas, and groundwater monitoring is summarized as follows:

- Infiltration monitoring
  - Soil moisture readings were obtained monthly from five neutron access tubes (NATs) at 0.3 m (1 ft) intervals to a depth of approximately 6 m (20 ft). Three NATs are associated with Landfill II with one NAT located on the landfill, and two NATs located adjacent to the landfill. On Landfill III, one NAT is located on the landfill, and one NAT is adjacent to the landfill.
  - Two time domain reflectometry (TDR) arrays obtained four sets of moisture data at 12-hour intervals from depths of 15 cm to 0.6 m (6 in. to 2 ft). One array was located at Landfill I and the other at Landfill II.
- Soil gas monitoring
  - Five soil gas monitoring locations were established near the landfills to monitor soil gas from four depths in the vadose zone at each location. The depths were near the soil-basalt interface (~3 m [10 ft]), in the basalt above the first interbed (~10 m [35 ft]), in the basalt below the first interbed (~21 m [70 ft]), and a deep sample approximately 9 m (30 ft) below the third depth (~30 m [100 ft]). Soil gas samples were collected approximately every 6 months.
- Groundwater monitoring
  - Eight monitoring wells in the vicinity of the landfills, referred to the landfill monitoring wells, were sampled quarterly. Three monitoring wells south of the landfills, known as the CFA facility monitoring wells, were also sampled quarterly.
  - Water level measurements were taken from 27 wells on a monthly basis from May 1996 to October 1998, to determine groundwater flow directions.

1.1 Purpose and Objective

The October 1995 ROD signed by the agencies included the selected remedy for the CFA Landfills I, II, and III that consisted of covering each landfill with a native soil cover and maintaining institutional controls. The contaminants of concern (COCs) for the ROD are listed in Table 1-1. The remedial action began in 1996 with the construction of soil covers and implementation of institutional controls.

Remedial action objectives (RAOs) in the landfills ROD included:

- Minimize the potential for erosion and infiltration at the surface
- Ensure that drinking water standards are not exceeded in the SRPA due to the migration of contaminants from the landfills.

To comply with these RAOs, the ROD required that the DOE-ID develop a plan to monitor infiltration through the soil covers, soil gas, and groundwater in the vicinity of the landfills. A monitoring plan was developed by DOE-ID during the remedial design phase (Tables 1-2 and 1-3). The monitoring plan called for two monitoring phases: (1) a 2-year intensive monitoring period, and (2) long-term monitoring through the end of the institutional control period of 30 years.

This report summarizes monitoring data collected from October 1996 through September 1998. The data were collected to provide trend data from the various monitoring components, establish a baseline of monitoring data, and support development of the long-term monitoring schedule and activities. This report also describes the integration of additional monitoring equipment installed as directed by the monitoring work plan (Neher 1997).

1.2 Site Background

1.2.1 History of the INEEL

The INEEL is a government-owned reservation managed by the U.S. Department of Energy (DOE). The eastern boundary of the INEEL is located 67 km (42 mi) west of Idaho Falls, Idaho. The INEEL site occupies approximately 890 mi^2 (2,305 km^2) of the northwestern portion of the Eastern Snake River Plain in southeast Idaho. The INEEL is nearly 62 km (39 mi) long from north to south and approximately 57 km (36 mi) wide in the southern portion, and includes portions of five Idaho counties (Bingham, Bonneville, Butte, Clark, and Jefferson). Figure 1-1 illustrates the INEEL configuration and some of its major facilities.

1.2.2 Regulatory History

The INEEL was added to the EPA's National Priorities List (NPL) of Superfund sites on November 21, 1989 (54 Federal Register [FR] 48184). A Federal Facility Agreement and Compliance Order (FFA/CO) for the INEEL was signed by the DOE-ID, EPA, and State of Idaho in December 1991 (DOE 1991). The goal of this agreement is to ensure that potential or actual INEEL releases of

Table 1-1. Contaminants of concern at OU 4-12.

Media	Landfill I (CFA-01)	Landfill II (CFA-02)	Landfill III (CFA-03)
Groundwater	Cadmium Zinc	Beryllium Cadmium Zinc	Cadmium Zinc
Soils	Polyaromatic Hydrocarbons Beryllium Co-60	Polyaromatic hydrocarbons	—

Table 1-2. Monitoring objectives at groundwater wells.

Well Number	Location	Analyte/Method	Water Level
LF 2-08	Downgradient of Landfill II (CFA-02)	VOCs, metals, anions, alkalinity	Yes
LF 2-09	Downgradient of Landfill II (CFA-02)	VOCs, metals, anions, alkalinity	Yes
LF 2-10	Downgradient of Landfill II (CFA-02)	VOCs, metals, anions, alkalinity	Yes
LF 2-11	Upgradient of Landfill II (CFA-02)	VOCs, metals, anions, alkalinity	Yes
LF 3-08	Downgradient of Landfills I And III (CFA-01 and CFA-03)	VOCs, metals, anions, alkalinity	Yes
LF 3-09	Downgradient of Landfills I And III (CFA-01 and CFA-02)	VOCs, metals, anions, alkalinity	Yes
LF 3-10	Adjacent to Landfill III (CFA-03)	VOCs, metals, anions, alkalinity	Yes
USGS 20	Obtain water level	none	Yes
USGS 34	Obtain water level	none	Yes
USGS 35	Obtain water level	none	Yes
USGS 36	Obtain water level	none	Yes
USGS 37	Obtain water level	none	Yes
USGS 38	Obtain water level	none	Yes
USGS 39	Obtain water level	none	Yes
USGS 57	Obtain water level	None	Yes
USGS 77	Obtain water level	none	Yes
USGS 82	Obtain water level	none	Yes
USGS 85	Upgradient of Landfills I and III (CFA-01 and CFA-03)	VOCs, metals, anions, alkalinity	Yes
USGS 111	Obtain water level	none	Yes
USGS 112	Obtain water level	none	Yes
USGS 113	Obtain water level	none	Yes
USGS 114	Obtain water level	none	Yes
USGS 115	Obtain water level	none	Yes
USGS 116	Obtain water level	none	Yes
CFA-MON-001	Downgradient of New Sewage Treatment Facility	VOCs, metals, anions, alkalinity	Yes
CFA-MON-002	Downgradient of New Sewage Treatment Facility	VOCs, metals, anions, alkalinity	Yes
CFA-MON-003	Downgradient of New Sewage Treatment Facility	VOCs, metals, anions, alkalinity	Yes

VOC = volatile organic compound

Table 1-3. Infiltration monitoring at OU 4-12.

Location	Soil Vapor Sampling Locations[a]	Neutron Probe Access Tubes	Time Domain Reflectometer
Landfill I	1	—	array
Landfill II	2	3	array
Landfill III	2	2	—

a. Four depths are sampled at each location. For example, four soil gas samples are collected from the one location at Landfill I.

hazardous substances to the environment are thoroughly investigated in accordance with the National Oil and Hazardous Substances Pollution Contingency Plan, and that appropriate response actions are taken as necessary to protect human health and the environment.

The requirement for monitoring of the landfills was established in the OU 4-12 ROD. The remedial design specified the manner in which monitoring of groundwater, cover infiltration, and the vadose zone would be carried out (Rothermel and Cotton 1996). The post-ROD monitoring work plan was designed to provide data for use in evaluating whether the remedial action objectives stated in the ROD are being met (Neher 1997). The monitoring work plan specified that agency review of monitoring data would take place at the end of the short-term (2-year) intensive monitoring phase.

1.2.3 CFA and Landfills I, II, and III

The CFA is located in the south-central portion of the INEEL, approximately 93 km (50 mi) west of the city of Idaho Falls, Idaho (see Figure 1-1). The original facilities at the CFA were built in the 1940s and 1950s to house U.S. Navy gunnery range personnel. The facilities have been modified over the years to fit the changing needs of the INEEL and now provide craft, office, service, and laboratory space. At present, approximately 820 people work at the CFA.

The CFA Landfills I, II, and III are located approximately 0.8 km (0.5 mi) north of the CFA proper. CFA Landfill I was operated as a disposal facility from the early 1950s until the mid 1980s. Landfill I covers a total surface area of approximately 3.33 ha (8.25 acres). Landfill I is composed of three major units, commonly referred to as the rubble landfill, the western waste trench, and the northern waste trench. Landfill II operated from 1970 until 1982 and was a fill operation encompassing 6 ha (15 acres) in the southwestern portion of an abandoned gravel pit. Landfill III encompasses 5 ha (12 acres) and was opened in October 1982 when operations at Landfill II were terminated. Landfill III consists of a covered landfill and an active pit area.

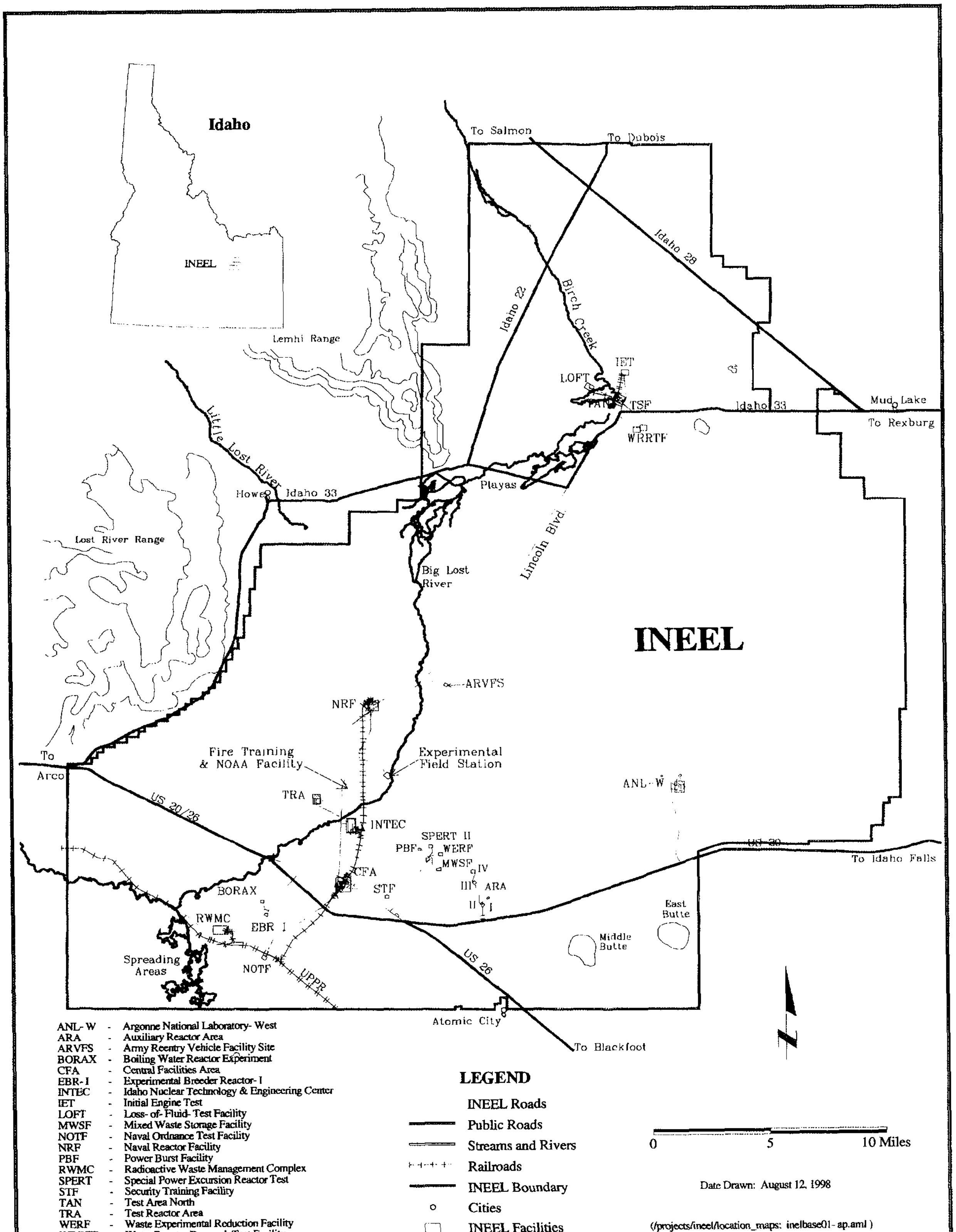

Figure 1-1. INEEL site map showing major facilities.

The predominant waste types disposed of in the landfills were construction, office, and cafeteria waste. Lesser amounts of potentially hazardous wastes, including waste oil, solvents, chemicals, and paint also entered the landfills. Sources of the wastes deposited in the landfills have been identified as including the Test Reactor Area (TRA), Argonne National Laboratory–West (ANL-W), the Naval Reactors Facility (NRF), Test Area North (TAN), the Idaho Nuclear Technology and Engineering Center (INTEC; formerly known as ICPP), the Auxiliary Reactor Area, the CFA, the Special Power Excursion Reactor Test, and the Experimental Breeder Reactor II.

1.3 Report Organization

Section 2 of this report presents a general description of the environmental setting of the INEEL and of WAG 4 (the CFA) in particular. Section 3 describes the methodology used to monitor the effectiveness of the soil covers and Section 4 describes the monitoring of the vadose zone and groundwater. Section 5 presents the conclusions of the investigation. Section 6 presents recommendations for further action. References are provided in Section 7.

2. ENVIRONMENTAL SETTING

2.1 Physical Geography

The INEEL is located on the northern edge of the Eastern Snake River Plain at the base of the Lost River Range, the Lemhi Range, and the Beaverhead Mountains of the Bitterroot Range. The Snake River Plain is the major physiographic feature of southern Idaho, stretching from the Oregon border almost to the Montana border, in a broad crescent ranging from 80 to 112 km (50 to 70 mi) wide, as shown in Figure 2-1. Altitude of the Snake River Plain at the INEEL ranges from 1,400 to 1,600 m (4,800 to 5,100 ft).

2.2 Geology

The geology of the INEEL is strongly influenced by the volcanic and seismic processes that created the Snake River Plain and the surrounding basin and range structures over the past 17 million years. The Lemhi, Beaverhead, and Lost River mountain ranges north of the INEEL (Figure 2-2) are composed of Paleozoic sedimentary rocks.

Unconsolidated surficial deposits of various ages and origins cover much of the INEEL, as shown in Figure 2-3. These include: alluvium along the Big Lost River, lacustrine (lake) deposits of clays, silts, and sands in the northern part of INEEL, and wind-deposited silts or loess up to approximately 6 m (20 ft) thick over much of the basalt bedrock at the INEEL (Scott 1982).

Aquifer characteristics are influenced by the relative thickness of the volcanic rock compared to sediment interbeds. Because of the concentration of volcanic activity along the axial volcanic zone (Figure 2-4) and along volcanic rift zones, these areas tend to be constructional highlands that have received less sediment deposition than other areas. Thus, the total thickness of sediments tends to be greater near the margins of the Eastern Snake River Plain (Whitehead 1986), and between volcanic rift zones. In fact, interbeds are not present in many of the drill holes along the axial volcanic zone. The combination of sparse interbeds and abundant shelly pahoehoe and pyroclastic material along the axial volcanic zone suggest the aquifer is more transmissive compared to elsewhere on the Eastern Snake River Plain.

2.2.1 Geology of Waste Area Group 4

The facilities at WAG 4 are situated on Big Lost River alluvial deposits (Figure 2-3). The alluvial deposits are underlain by thick sequences of interfingering basalt lava flows and thin sedimentary interbeds, as shown in the geologic cross-sections taken from well log data in Figures 2-5 and 2-6. The locations of the cross-sections are shown on Figure 2-7. The sequence of basalt flows and interbedded sediments extends well below the water table to a depth of several thousand feet. Basalt lava-flow groups, separated by sedimentary interbeds, are composed of numerous basalt lava flows that erupted from one or more vents. The basalts may be fine or coarse-grained, vesicular or nonvesicular, fractured or jointed. Some fractures and vesicles may be filled with sedimentary material or secondary calcite.

Sedimentary interbeds at depths underlying the CFA consist predominantly of fine-grained silts of eolian origin, and clays, silts, sands, and gravels (the last-named is relatively uncommon in the interbedded sediments) deposited by streams such as the Big Lost River. Subsurface sedimentary interbeds are lithologically similar to surficial sediments, and past depositional processes and systems are inferred to have been similar to those of recent times (Bartholomay 1990).

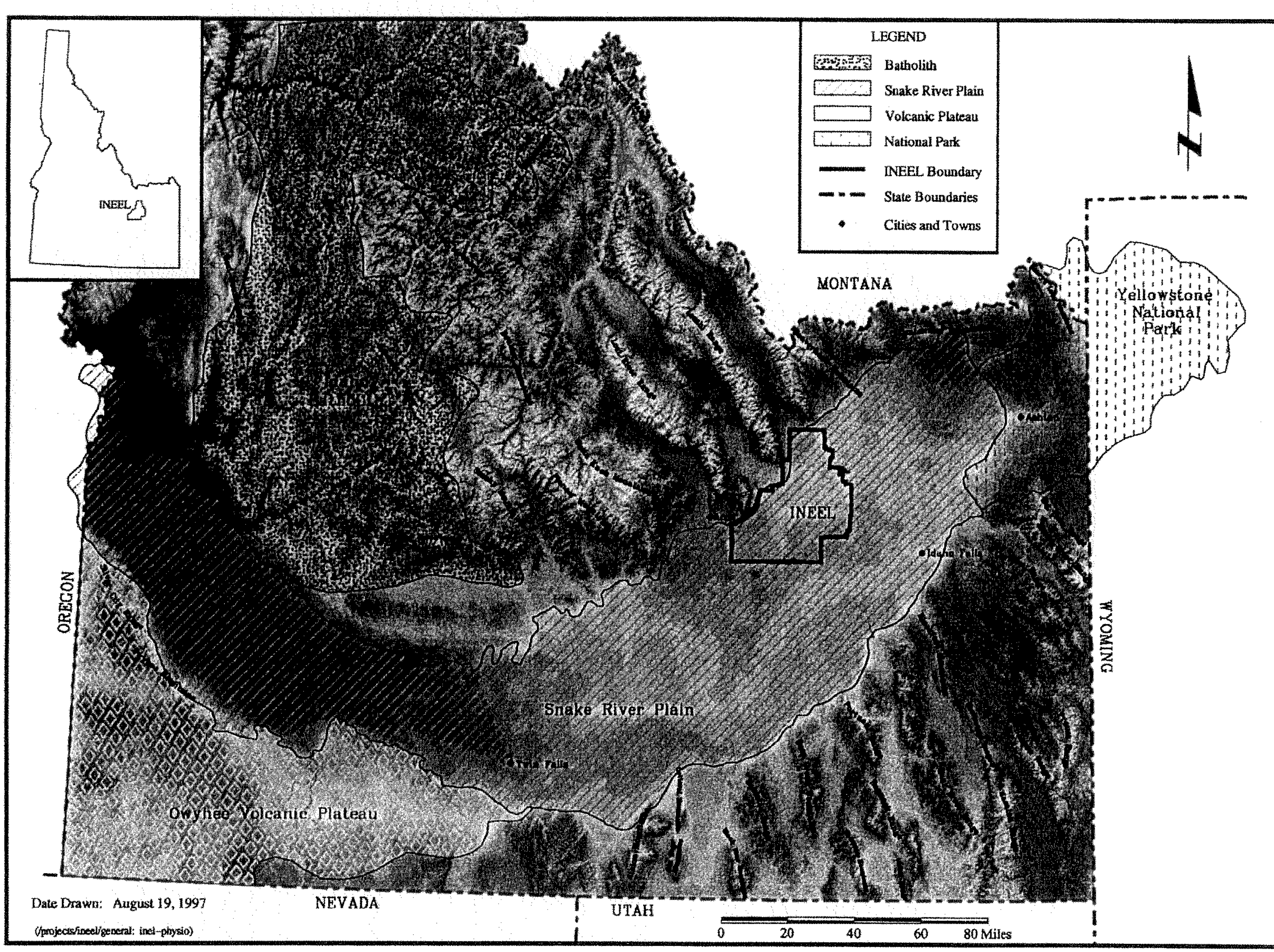

Figure 2-1. Physiographic features of the INEEL area.

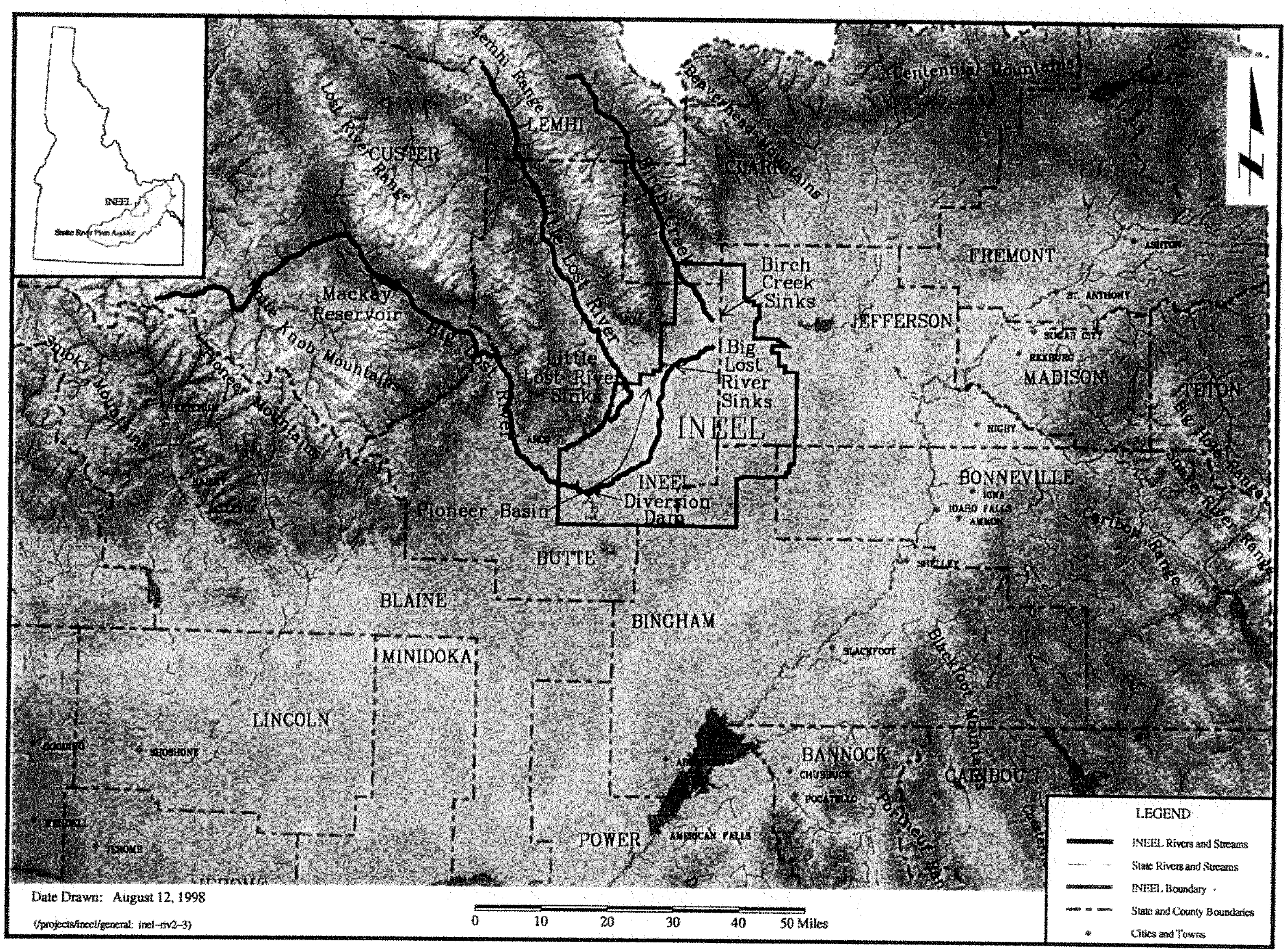

Figure 2-2. Index map of the Western Snake River Plain (modified from Hackett et al. 1982).

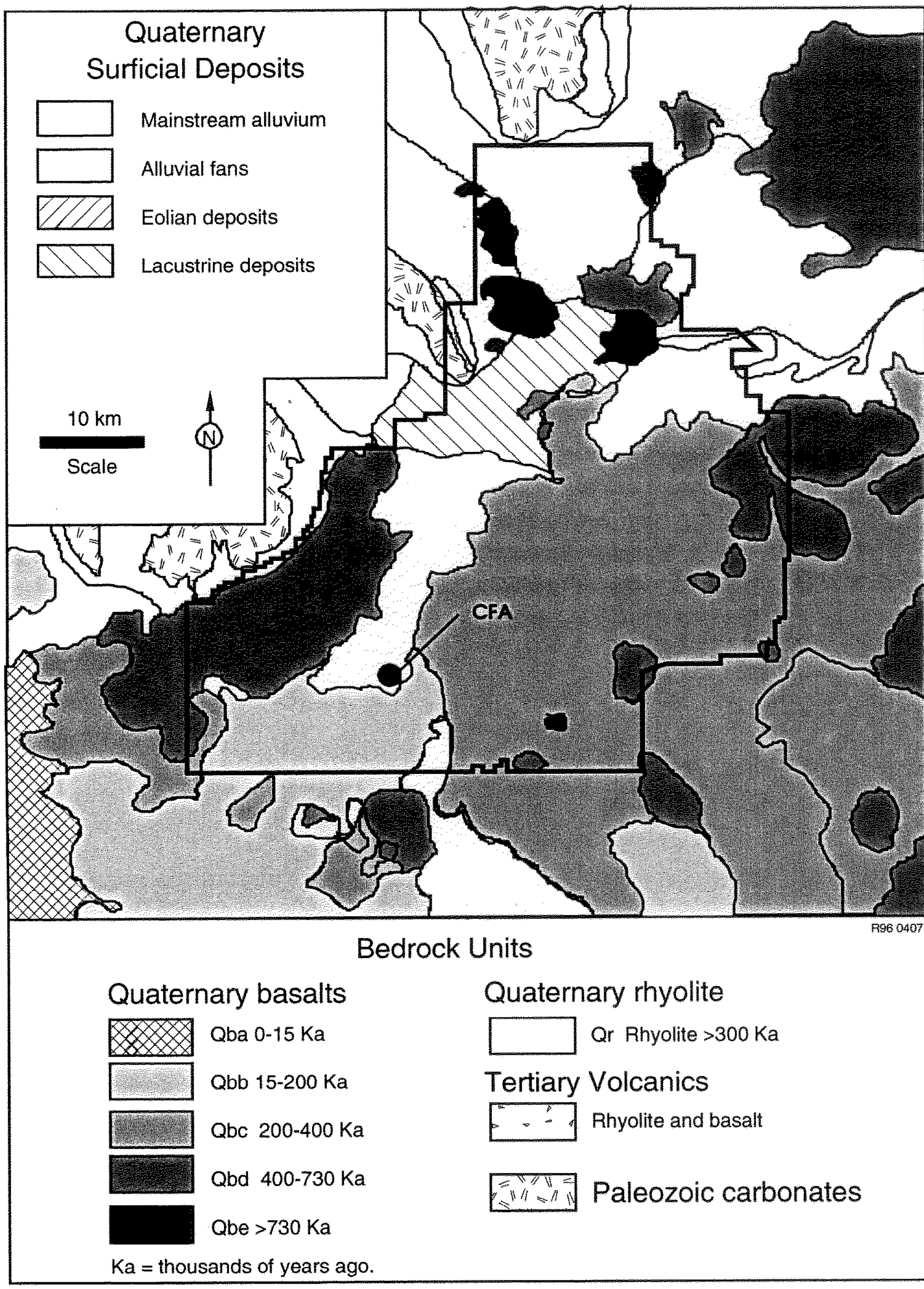

Figure 2-3. Generalized geologic map of the INEEL area, showing CFA in relation to the surficial distribution of major basalt-lava-flow groups and sedimentary deposits (Kuntz et al. 1990, Scott 1982) (R960407).

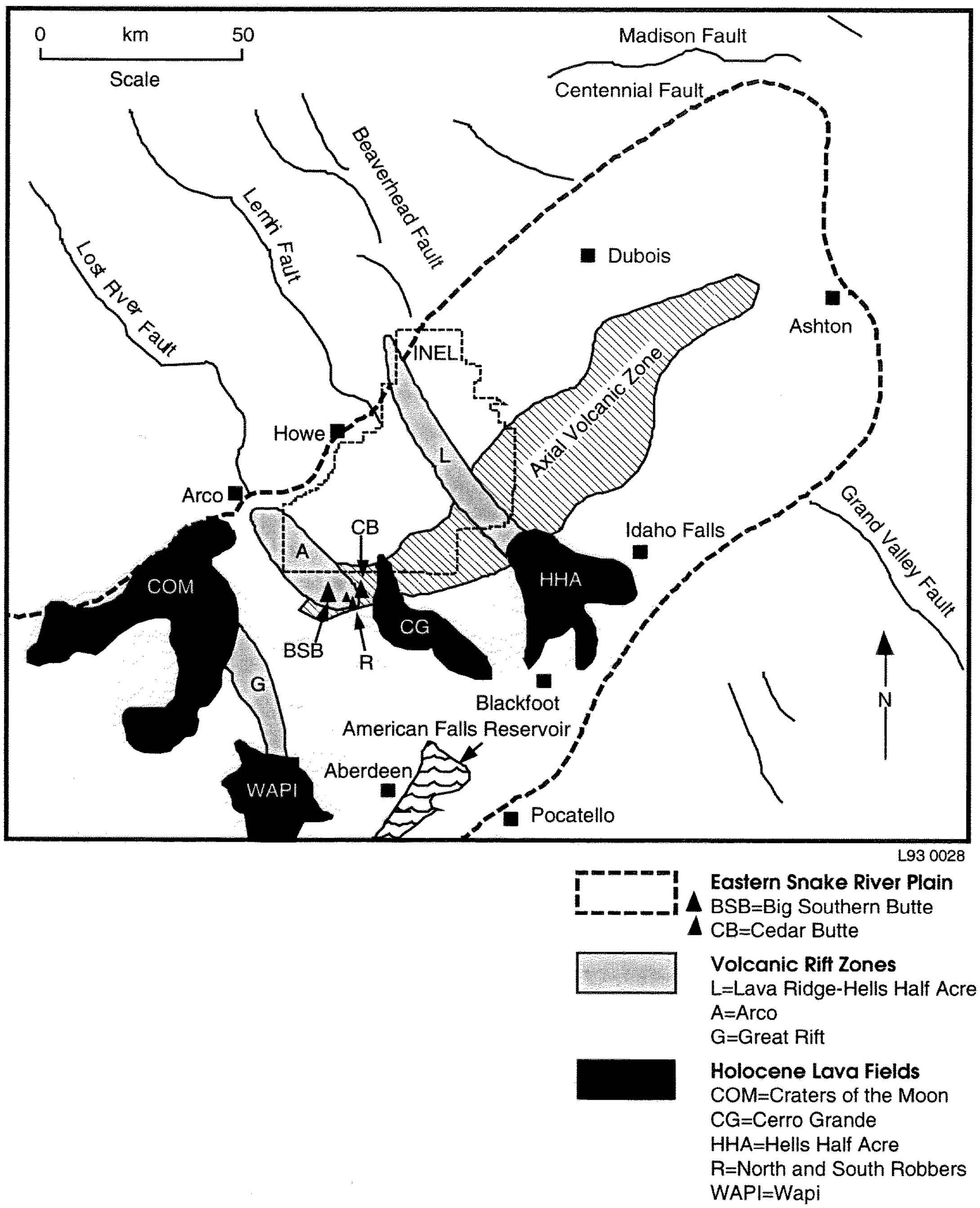

Figure 2-4. Illustration of the axial volcanic zone (L93 0028).

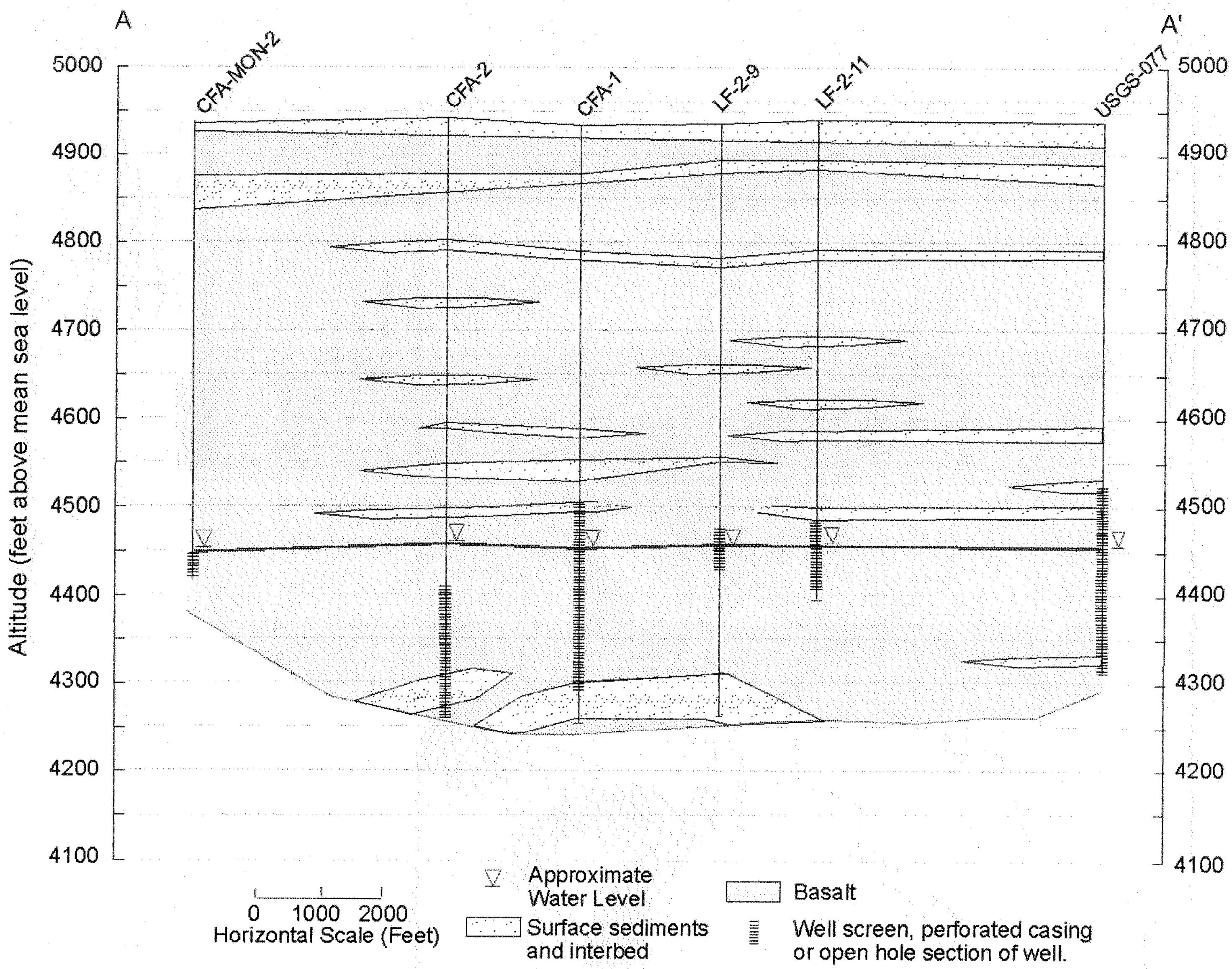

Figure 2-5. Cross-section A-A through Central Facilities Area.

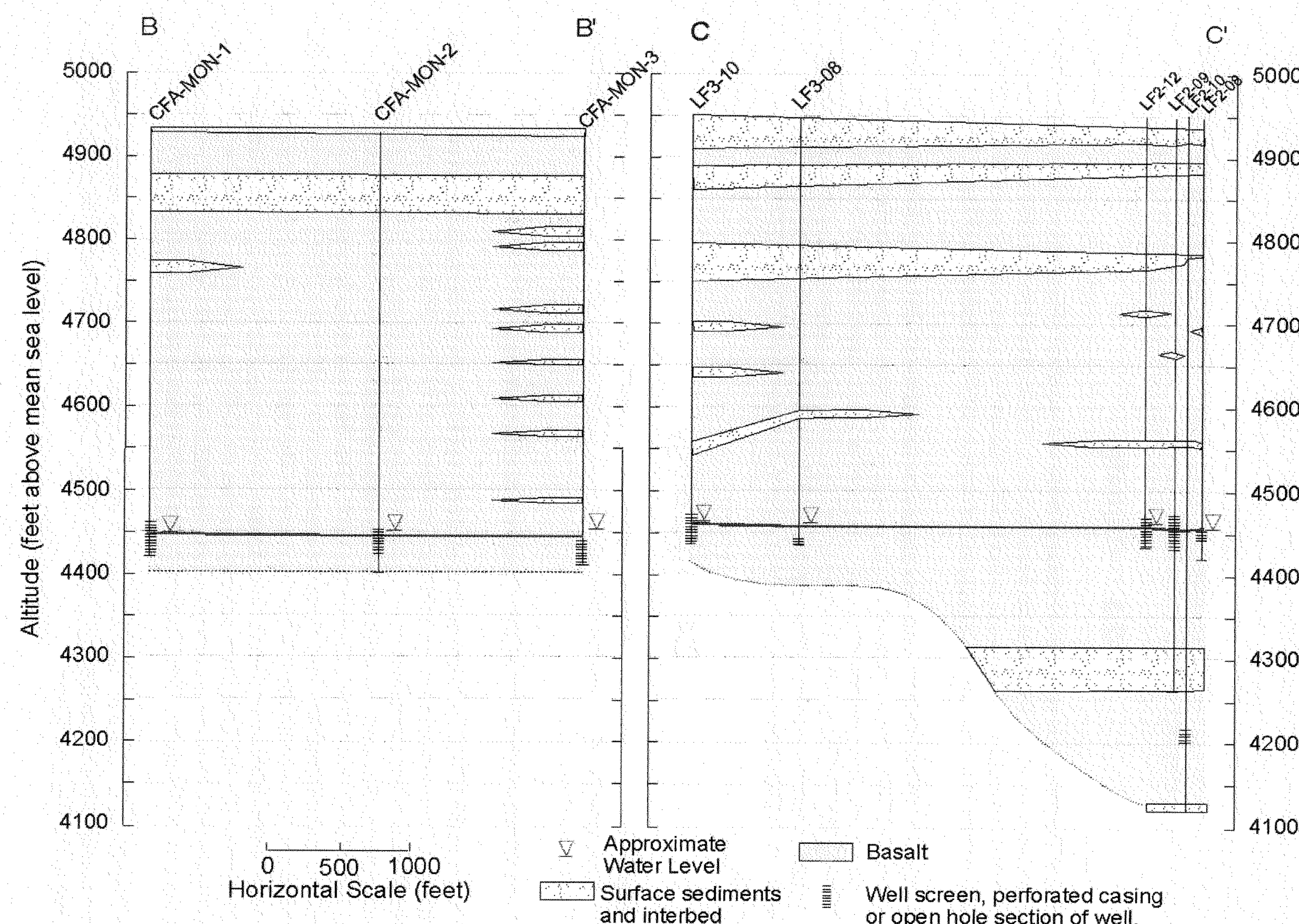

Figure 2-6. Location of stratigraphic cross-sections in the vicinity of the CFA landfills.

Interbeds with relatively high clay content may provide a barrier against the possible migration of contaminant leachate from WAG 4 release sites (Figures 2-5, 2-6 and 2-7). Such interbeds impede the downward migration of water and contaminants to the water table by a combination of their low permeability and high adsorptive capacity. However, many of the interbeds shown in Figure 2-6 and observed in wells at the landfills are thin and discontinuous and are not able to be correlated between drill holes. Table 2-1 indicates the depths of interbed clay as observed in the field during drilling of monitoring wells in the vicinity of Landfills II and III.

2.3 Climate

The climate at the INEEL is semiarid, with large daily and seasonal temperature fluctuations. The average annual precipitation at the INEEL is 21.5 cm (8.5 in.). The highest precipitation rates occur during the months of May and June. Snowfall at the INEEL has had an annual average of 66 cm (26 in.). Snowfall typically occurs in the months of November through April (Van Deusen and Trout 1990).

Potential annual evaporation from saturated ground surface at the INEEL is approximately 91 cm (36 in.) (Clawson et al. 1989). Eighty percent of this evaporation occurs between May and October. During the warmest month, July, the potential daily evaporation rate is approximately 0.63 cm/day (0.25 in./day). During the coldest months, December through February, evaporation is low and may be insignificant. Actual evaporation from native vegetation at the INEEL parallels the total annual precipitation input. Potential evapotranspiration is at least three times greater than actual evapotranspiration.

2.4 Hydrology

This section provides an overview of the hydrology at the INEEL with an emphasis on the hydrology in the CFA vicinity. This section summarizes work performed by the U.S. Geological Survey (USGS) and DOE contractors.

2.4.1 Surface Water Hydrology at the Central Facilities Area

Surface water at the INEEL consists of three streams: the Big Lost River, the Little Lost River, and Birch Creek, draining intermountain valleys north and northwest of the site (Figure 2-2). Surface water flowing onto the INEEL either evaporates or infiltrates into the ground because the INEEL lies within a closed topographic basin. Streamflows from two of the three streams that reach the INEEL, the Little Lost River and Birch Creek, have little effect on the CFA. The Big Lost River is often depleted by irrigation diversions and infiltration losses along the river before it reaches the INEEL. Prior to 1993, the Big Lost River had not flowed onto the INEEL since 1986. This was due to the prolonged drought conditions in southeastern Idaho over the previous 5 years, which led to increased upstream irrigation demands. When flow in the Big Lost River actually reaches the INEEL, it is either diverted at a diversion dam (Figure 2-8), or flows northward across the INEEL in a shallow, gravel-filled channel to its terminus at the Lost River sinks. Here, its flow is lost to evaporation and infiltration.

The Big Lost River is approximately 2.4 km (1.5 mi) northwest of the CFA at its nearest point. The CFA has no potential impact on the Big Lost River as the CFAs runoff infiltrates the desert floor with no discharge to the Big Lost River.

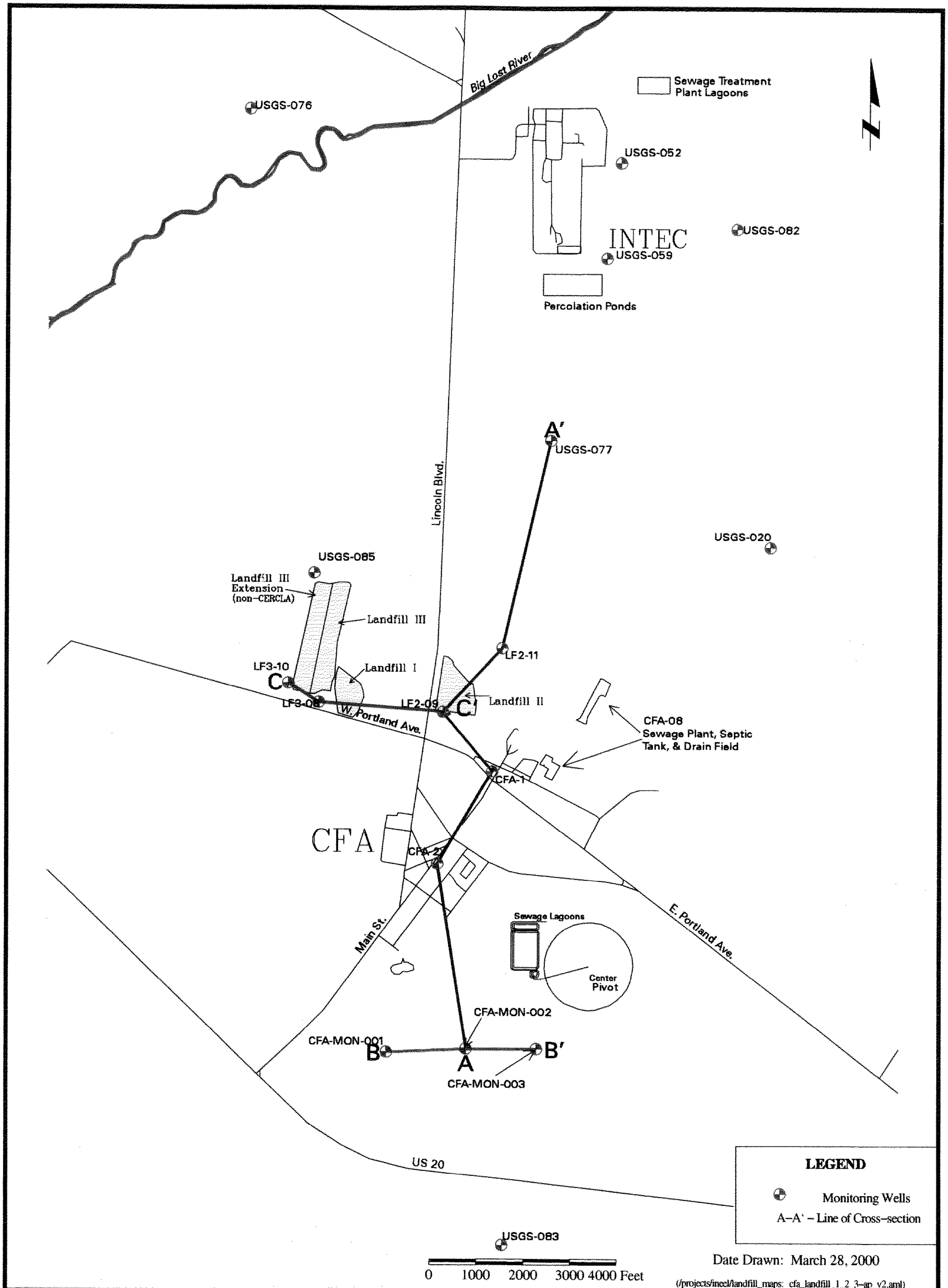

Figure 2-7. Location of stratigraphic cross–sections in the vicinity of the CFA landfills.

Table 2-1. Depths of clay in sedimentary interbeds observed in monitoring wells at CFA Landfills II and III.

Landfill	Monitoring Well	Depth Interval of Clay Layer (ft bgs)[a]	Material[b]
II	LF2-08	185 to 200	Clay
		372 to 385	Sandy, clayey silt
	LF2-09	45 to 65	Sand, clay
		370 to 385	Silt and clay
		625 to 645	Silt and clay
	LF2-10	50 to 65	Clay with trace of silt and sand
		148 to 149	Clay
	LF2-12	195 to 197	Clay, sandy
III	LF3-08	150 to 167	Silt/clay
		185 to 200	Silt/clay
	LF3-10	55 to 70	Sand, cinders changing to sand with 25% clay
		90 to 97	Sand with 20% clay
		150 to 190	Sand with 0–3% clay
		240 to 250	Sand with 20–30% clay
	LF3-11	405 to 415	Sand with silt and clay
	LF3-11	128 to 135	Clay, silty with basalt
		190 to 192	Clay/silt
		352 to 362	Sand, clay
		410 to 420	Sand with clay and silt
	USGS-85	55 to 65	Clay
		95 to 100	Clay and basalt
		145 to 165	Basalt and clay
		170 to 200	Basalt and clay
		298 to 302	Clay
		345 to 355	Clay
		515 to 520	Broken basalt and clay
		612 to 622	Clay

a. Depths are approximate.

b. The classification of the soil materials is based on a geologist's field observations made during drilling.

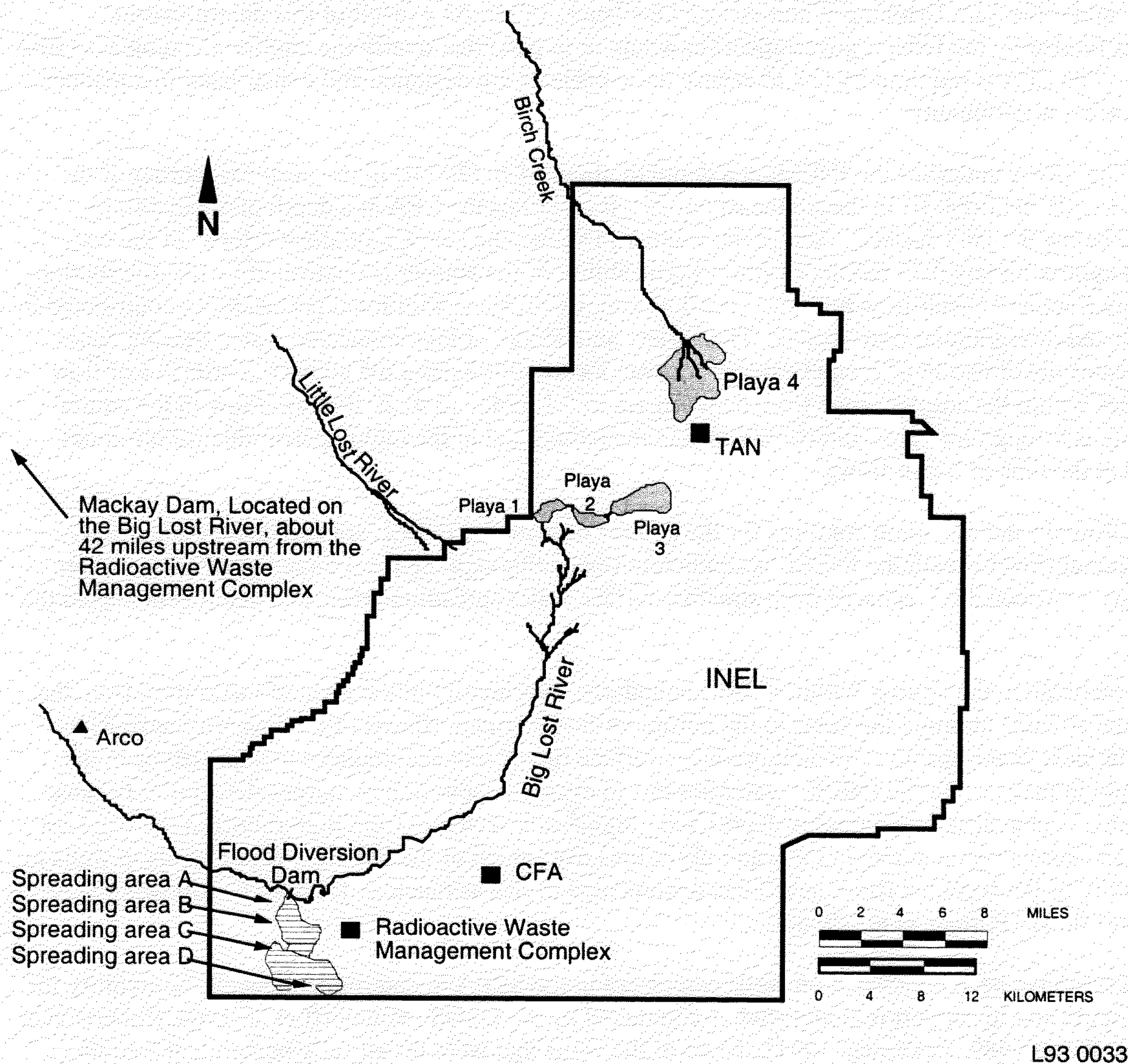

Figure 2-8. Map showing surface water features near or on the INEEL (L93 0033).

2.4.2 Regional Groundwater Hydrology

The SRPA, one of the largest and most productive groundwater resources in the United States, underlies the INEEL and is listed as a Class I aquifer. The EPA designated the aquifer as a sole-source aquifer under the Safe Drinking Water Act on October 7, 1991. As a result of this determination, projects funded by the federal government (in whole or in part) that overly the aquifer are subject to EPA review. The EPA is required by law to ensure these projects are designed and constructed in a manner that protects water quality.

The SRPA underlies the INEEL at a depth of about 61 m (200 ft) in the northeast corner of the INEEL to 305 m (1,000 ft) in the southeast corner. It underlies the CFA at a depth of about 146 m (480 ft) below the land surface. Across the southern INEEL, the average gradient (slope) of the water table is approximately 0.75 m/km (4 ft/mi). Permeability of the aquifer is controlled by the distribution of highly fractured basalt flow tops and interflow zones with some additional permeability contributed by vesicles and intergranular pore spaces. The variety and degree of interconnected water-bearing zones complicates the direction of groundwater movement locally throughout the aquifer. Estimates of flow velocities within the aquifer range from between 1.5 to 6.1 m/day (5 to 20 ft/day). Flow in the aquifer primarily is through fractures, interflow zones in the basalt, and in the highly permeable rubble zones located at the tops of basalt flows.

Groundwater elevation contours for the aquifer beneath the INEEL are depicted on Figure 2-9. The regional flow beneath the INEEL is south-southwest, although the local direction of groundwater flow may be affected by recharge from streams, surface water spreading areas, and heterogeneities in the aquifer.

Recharge to the aquifer within INEEL boundaries is primarily in the form of infiltration from the rivers and streams draining the areas to the north, northwest, and northeast of the Eastern Snake River Plain. In most years, spring snowmelt produces surface runoff that accumulates in depressions in the basalt and in playas. On the INEEL, water not lost to evapotranspiration recharges the aquifer because the INEEL is in a closed topographic depression. Significant recharge from high runoff in the Big Lost River can cause a regional rise in the water elevations over much of the INEEL. Water levels in wells in the vicinity of the Big Lost River have been documented to rise as much as 1.8 m (6 ft) following very high river flows (Pittman et al. 1988).

Tests have been conducted on wells completed in the SRPA to determine the wells' suitability for water supply and to support regional studies conducted by the USGS (Mundorff et al. 1964, Robertson et al. 1974, Wood 1989, Ackerman 1991). None of the wells that were tested fully penetrate the aquifer; therefore, the transmissivity of the local aquifer in the vicinity of the CFA may be somewhat higher. The results of the aquifer tests demonstrate that the aquifer is not homogeneous and isotropic, and that there is considerable variation in the transmissivity and hydraulic conductivity of the aquifer at the CFA (Table 2-2).

2.4.3 Groundwater Hydrology at Waste Area Group 4

The USGS has maintained a groundwater monitoring network since 1949 at the INEEL to characterize the occurrence, movement, and quality of water in the SRPA, and to delineate the movement of facility-related wastes in the SRPA. This network consists of a series of wells from which periodic water-level and water-quality data are obtained. Data from the monitoring network are on file at the USGS INEEL Project Office. Nine groundwater monitoring wells are installed in the northern portion of

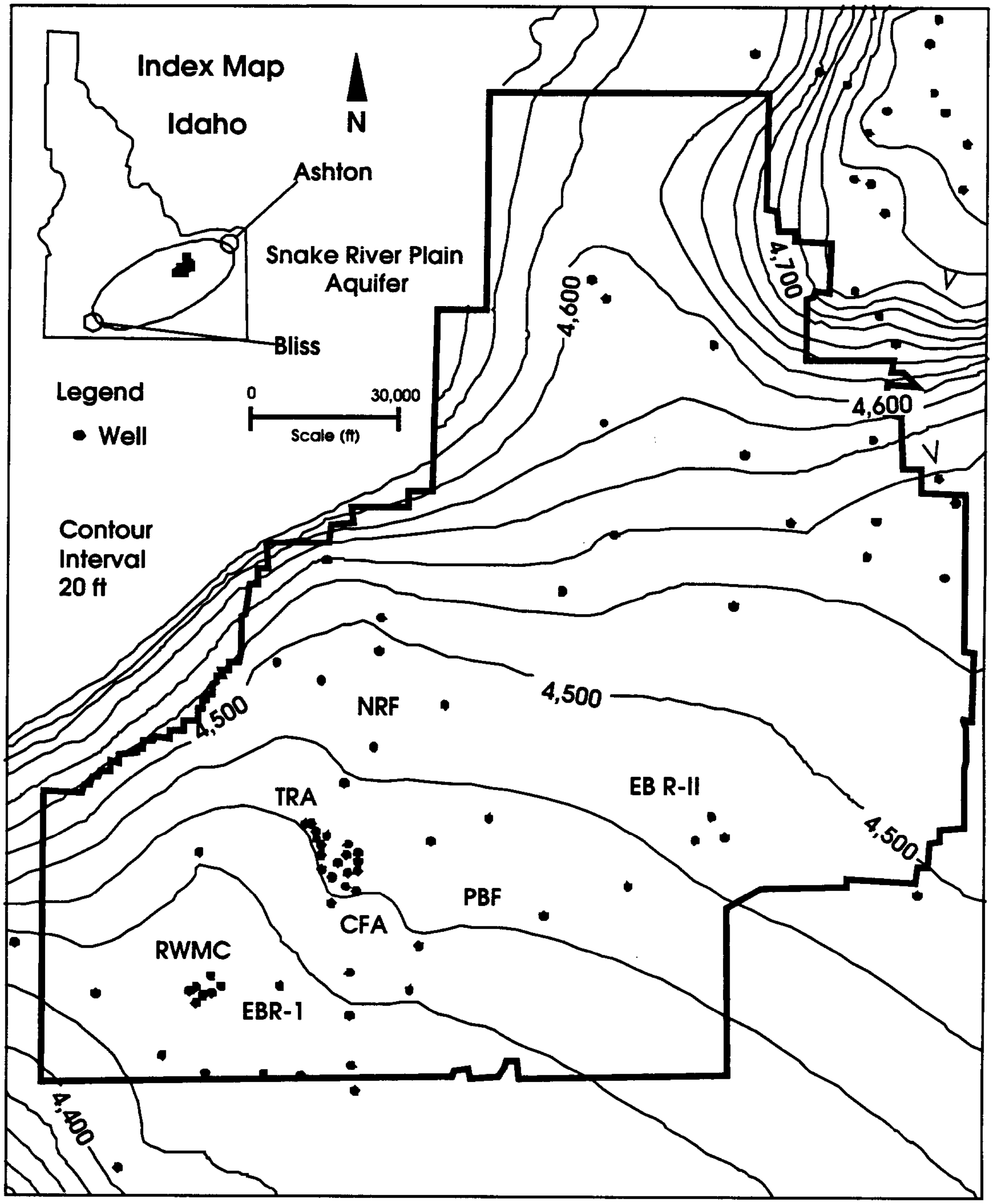

Figure 2-9. Groundwater elevation of Snake River Plain Aquifer (J960145).

Table 2-2. Transmissivity values for wells in the WAG 4 area, based on pumping test evaluations.[a]

Well Name	Completion Zone (ft bgs)	Date of Test	Transmissivity (ft^2/day)
CFA-2	521 to 651 661 to 681	2/27/51	170
CPP-1	459.9 to 485.9 527.4 to 576.8	8/12/81	73,000
CPP-2	458.3 to 483.3 551.1 to 600.25	8/14/81	160,000
CPP-3	412 to 452 490 to 593	9/27/51	760,000
USGS-37	507 to 571.5	7/7/87	16,000
USGS-40	456 to 678.8	7/28/87	87,000
USGS-43	450.5 to 675.8	7/29/87	80,000
USGS-51	475 to 659	6/26/87	2,900
USGS-57	477 to 732	6/24/87	28,000
USGS-76	457 to 718	6/10/87	190,000
USGS-82	469 to 561	6/26/87	56,000
USGS-111	440 to 600	5/20/87	22
USGS-112	432 to 563	5/26/87	64,000
USGS-113	445 to 564	6/1/87	190,000
USGS-114	440 to 564	5/21/87	10
USGS-115	440 to 581	5/22/87	32
USGS-116	400 to 580	5/29/87	150

a. Ackerman 1991.

the CFA. The wells were installed to monitor the CFA landfills at both upgradient and downgradient locations. The depth to groundwater in these wells varies from approximately 145 m (476 ft) at LF 2-08 to just over 150 m (495 ft) at LF 3-08. The hydraulic gradient for the regional aquifer in the vicinity of the CFA is approximately 0.2 m/km (1 ft/mi) (Lewis and Jensen 1984). Aquifer storage ability was calculated in the vicinity of the landfills using LF 2-11 and LF 3-11 based on barometric efficiency and provided an estimate of 0.0003.

Water in the SRPA shows a chemical composition reflecting the source area of the aquifer's recharge (Robertson et al. 1974). Recharge from the north and northwest is derived from clastic and carbonate sedimentary rocks and is accordingly a calcium bicarbonate-type water. Recharge from the east is derived from siliceous volcanic rocks and is somewhat higher in sodium, fluoride, and silica.

Groundwater at the CFA landfills is of the calcium bicarbonate-type indicative of recharge from the north and northwest.

Documented instances of groundwater degradation at the INEEL have occurred from past waste disposal practices. Radionuclide and chemical constituents detected in the aquifer include: Sr-90, Co-60, Cs-137, Pu-238, Pu-239, Pu-240 (undivided), Am-241, tritium, total chromium, sodium, chloride, nitrate, and trichloroethene (Orr and Cecil 1991). Tritium and chromium have been detected in the groundwater collected from monitoring wells upgradient and downgradient of the CFA (DOE-ID 1997a). A major source of this groundwater contamination is due to past waste-disposal practices at INTEC and the TRA, two facilities upgradient of the CFA.

The source of drinking water for site employees at the CFA consists of two production wells (CFA-1 and CFA-2). A drinking water program was initiated in 1988 to monitor drinking water wells on the INEEL for compliance with community water system standards as established by EPA and State of Idaho regulations, as well as applicable DOE orders. Under this program, waters from production wells CFA-1 and CFA-2 are analyzed for radionuclides (gross alpha, beta, and tritium), organics, inorganics (nitrates), and metals.

2.4.4 Perched Water at Waste Area Group 4

During the OU 4-12 remedial investigation, boreholes were drilled into the underlying basalt at Landfill II to determine if leachate from the landfill was present. No perched water body was encountered in the drilling or sampling of these boreholes, or during the previous (1987) drilling investigations at Landfills II and III.

Two perched water zones existed beneath the Sewage Treatment Plant Drainfield (CFA-08) from 1944 through 1995. These zones were the result of wastewater discharged to the sewage treatment plant drainfield during this period. The lower perched water zone dissipated by June 1996 and the upper perched water dissipated by January 1997.

3. MONITORING METHODOLOGY

3.1 Objectives

The post-ROD monitoring work plan (Neher 1997) identifies specific requirements for the 2-year intensive monitoring period. The monitoring plan was designed to provide data for use in evaluating whether the remedial action (native soil covers) continues to meet the remedial action objectives stated in the ROD. In particular, monitoring program data will be used to evaluate the remedial action objectives to minimize infiltration and ensure that drinking water standards are not exceeded in the SRPA due to migration of contaminants from the landfills.

Key objectives of the monitoring effort were to:

- Monitor infiltration of moisture through the landfill covers
- Monitor soil-gas volatile organic compounds (VOCs) and methane concentrations in the vadose zone near each landfill
- Monitor concentrations of contaminants in the groundwater in the vicinity of the landfills
- Establish a baseline of potential contaminant concentrations in the aquifer against which future data can be compared
- Monitor groundwater flow direction in the aquifer in the vicinity of the landfills.

The 2-year intensive monitoring phase (short-term monitoring) is designed to integrate additional monitoring activities, provide trend data from the various monitoring components to establish baseline monitoring data, and support development of the long-term monitoring schedule and activities.

3.1.1 Action Levels

To ensure the effectiveness of the soil cover, the monitoring system was designed to provide early detection of a potential release to the surface or groundwater. Action levels are established as performance criteria by which the effectiveness of the soil cover will be measured; exceeding an action level will trigger reevaluation of the selected remedy.

Based upon existing information, regulatory requirements, and regulatory guidance, an action level for groundwater concentrations that would provoke reevaluation of the remedial actions includes:

- Monitoring results for groundwater contaminants attributable to the landfills that exceed maximum contaminant level (MCLs). Contaminants detected below or downgradient of the landfills, with a higher (statistically significant above the 95% confidence level) concentration than from upgradient of the landfills may be considered attributable to the landfills.

The action levels for groundwater contaminant concentrations are based upon existing regulatory requirements (i.e., drinking water MCLs). The work plan proposed establishing an action level for moisture infiltration rates and vadose zone gas concentrations following review of data from this 2-year intensive monitoring phase by the agencies.

3.1.2 Infiltration Monitoring Objectives

Vadose zone monitoring includes both TDR and neutron moisture probe monitoring. The objectives for vadose zone monitoring included:

- Document the landfill covers' effectiveness at minimizing infiltration into the landfill wastes. The infiltration monitoring system was designed to monitor infiltration through the landfill cover to the top of bedrock beneath the waste in selected locations. Neutron moisture probe and TDR measurements were used to monitor infiltration.

3.1.3 Soil Gas Monitoring Objectives

- Provide data to evaluate potential leaching of VOCs from the buried landfill waste at each of the landfills through the collection and analysis of soil gas samples. The VOC sampling plan was designed to detect VOCs both above and below the first interbed beneath the landfills (the first interbed is located at approximately 14 m [45 ft] below land surface).

3.1.4 Groundwater Monitoring Objectives

The objectives for groundwater monitoring included:

1. Provide data to evaluate potential leaching of contaminants to the SRPA.

2. Establish a baseline of potential contaminant concentrations in the aquifer against which future data could be compared. Potential contaminant impacts to the aquifer from the CFA landfills were assessed through the collection of groundwater samples from existing groundwater wells in the vicinity of the landfills.

3. Monitor the groundwater flow direction in the vicinity of the landfills.

Objectives of the analysis are to identify long- and short-term groundwater trends and the magnitude and direction of the groundwater flow on a local scale beneath the CFA.

3.2 Implementation of Monitoring Plan

3.2.1 Infiltration Monitoring

Prior to initiation of remedial actions, existing infiltration monitoring equipment installed at Landfills II and III included five neutron probe access tubes (to a depth of 5.5 to 7 m [18.2 to 23 ft] below land surface), heat dissipation block sensors, and salinity sensors. No infiltration or soil gas monitoring equipment was in place at Landfill I.

The heat dissipation block sensors and salinity sensors were cut off at land surface and abandoned. During the remedial investigation/feasibility study of the landfills, neither instrument array produced data that was of significant value for continued monitoring of soil moisture at the CFA landfills. Use of the neutron probe access tubes continued, and TDR arrays were added.

3.2.1.1 Neutron Moisture Probe Technique and Data Collection. The neutron moisture probe indirectly measures the moisture content of soils. A fast neutron source is lowered down an access tube. The fast neutrons emitted by the probe are slowed by hydrogen nuclei in the soil. A detector in the neutron moisture probe counts the slowed or thermalized neutrons. The counts are correlated to the amount of moisture in the soil, because the primary source of hydrogen in most soils is water. Other materials that contain hydrogen, such as plastics and hydrocarbons, can interfere with moisture measurements.

The change in number of counts is used to determine the movement of moisture in the soil profile. Movement of moisture in the soil column is determined from the difference of the number of counts from one measurement to the next at a given depth. To determine change in moisture, counts must be compared to counts taken from the same location throughout time. An increase in counts at a given depth over time indicates an increase in moisture. A decrease in counts over time indicates a reduction in moisture. Appendix A describe the moisture content calculation in much more detail.

The accuracy or reproducibility of neutron probe data by the Campbell Pacific Nuclear (CPN) Corporation varies depending on conditions. In ideal conditions, the neutron data is generally reproducible within 3% (Kramer 1992). Outside temperature, weather, temperature, equilibration time, and other conditions may decrease the reproducibility of the neutron data. Neutron moisture probe logs are approximations of true infiltration values because:

- Limited range of data used to developed the calibration curves
- Mass water contents were converted to volumetric water contents using an average soil bulk density for each soil type instead of actual measured densities from each location
- Moisture monitoring was conducted monthly that may miss moisture movement.

Therefore, the numbers presented in this report are approximations of water quantity.

3.2.1.1.1 Neutron Access Tubes—The NATs provide access through the soil for the moisture gauge. At the landfills, 3.8 cm (1.5 in.) steel pipe was driven through the surface soils to basalt, minimizing the annular space. Because the depth of interrogation of the neutron probe is limited by the strength of the neutron source, neutron-probe access tubes are constructed with minimal annular space to get the neutron source as close as possible to the target. This method of driving the casing has the advantage of obtaining depth without an annular space typically caused by drilling. The drawback to the driven-casing method is that soils become compacted immediately adjacent to the casing, which alters the soil's ability to hold and/or maintain soil water. Tube installation methods may affect the data collected from the moisture gauge. However, the NATs installed at the landfills appear to be functioning properly.

Five NATs were installed at CFA Landfills II and III in 1987 as part of a project responding to Resource Conservation and Recovery Act (RCRA) regulations. Figure 3-1 shows the NATs' locations. Three NATs were installed at Landfill II (LF2-03, LF2-04, and LF2-07) and two were installed at Landfill III (LF3-03 and LF3-05). The NATs were installed by driving 3.81-cm (1.5-in.). Inner diameter carbon steel tubes with a sealed point through the sediments to refusal. One NAT (LF2-07) was installed directly through waste (Ansley et al. 1988).

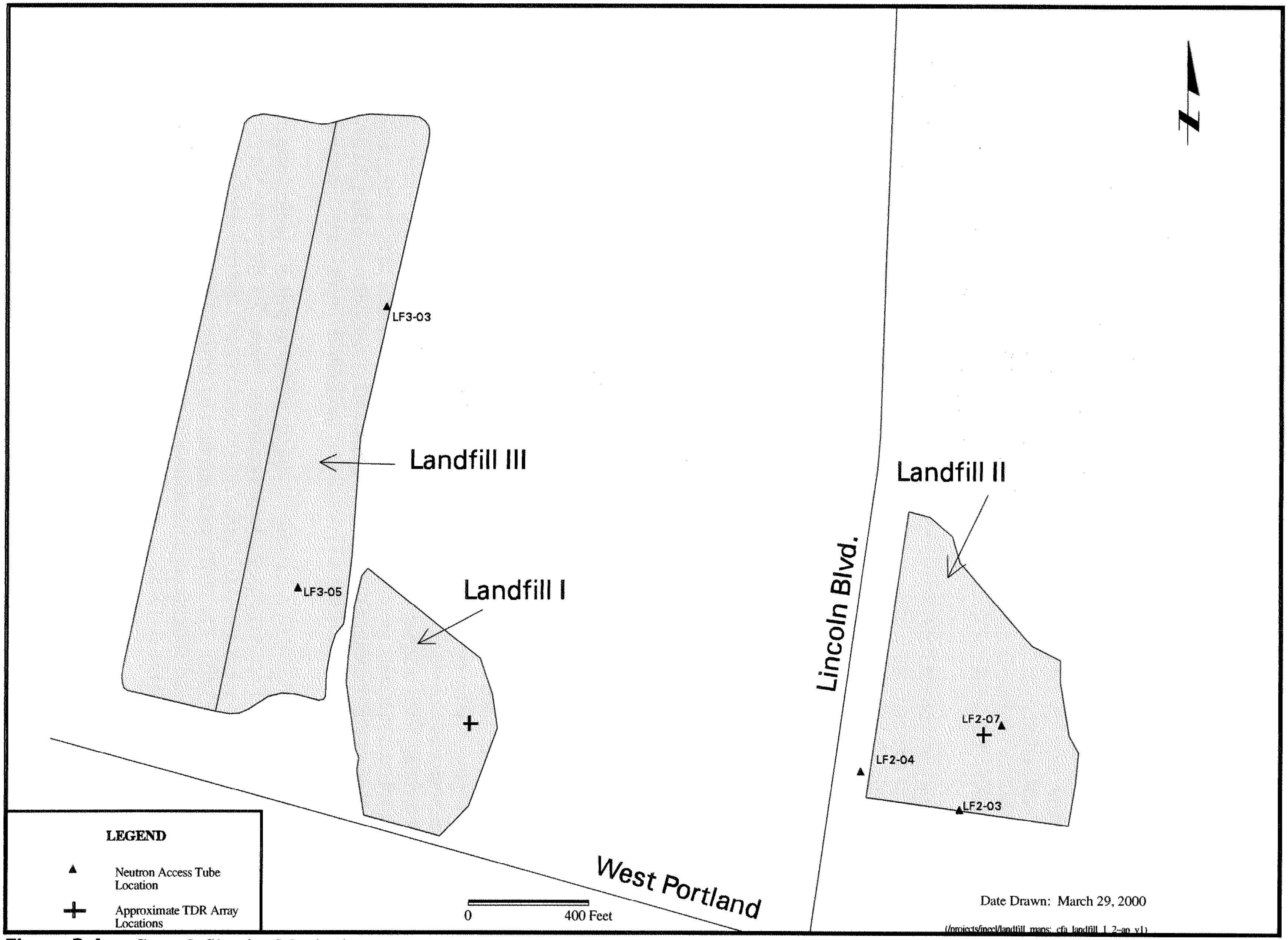

Figure 3-1. Cover Infiltration Monitoring

Since installation in 1987, monitoring of the five CFA Landfill NATs has been intermittent. Monthly monitoring was conducted from January 1988 to January 1991 and from June 1993 to December 1993. Monitoring of the NATs began again in July 1996 and has continued monthly until September 1998, except for October 1997, when the battery inside the neutron moisture gauge malfunctioned. Analysis of the data prior to July 1996, is presented in Ansley et al. 1988 and Keck et al. 1994.

The native soil cover was added to two NAT areas (LF2-07 and LF3-05) between July and November 1996. The soil cover around the NATs and inside the guard posts surrounding the NATs were emplaced with the same compaction requirements as the general soil cover. Gasoline-powered hand tampers were used to emplace and compact the soil cover near the NATs, because large equipment lacked mobility and could potentially damage the NATs. As the soil cover was added, it was necessary to extend the NAT casing therefore, the total depths of NATs LF3-05 and LF2-07 have increased since their original installation to accommodate the addition of the soil cover. Three of the NATs (LF2-03, LF2-04, and LF3-03) are located adjacent to the native soil cover. Casing was also extended on LF3-03, and soil was added. However, LF3-03 was not considered part of the soil cover in this report, because it lies on the edge of the native soil cover and did not receive the full 0.6 m (2 ft) of cover material.

3.2.1.1.2 Neutron Probe Calibration, Measurement, and Interpretation—A CPN Model 503DR hydroprobe (Serial Number W3Am001) was used to monitor the moisture in the landfill soils. During the July 1996 to September 1998 monitoring period, readings were taken at fixed 0.30-m (1-ft) intervals, using 16-second counts. Measurements (counts) were recorded in a field notebook and in the neutron moisture probe datalogger.

The CPN hydroprobes were calibrated to a nearby well because NATs were driven, not bored with the soil formation surrounding the access tube. The calibrations are typically conducted during borehole drilling.. The monthly differences in counts are converted to percent moisture and then into inches of water per sample interval. The change in moisture is determined by a positive difference (increase in moisture) or a negative difference (decrease in moisture). A discussion of this conversion is found in Appendix A.

The goal of the neutron-probe monitoring is to calculate the volume of water passing through the landfill cover, through the surficial sediments, and into the basalt. The first step of this process is to determine the maximum depth of evapotranspiration. This depth is generally related to the rooting depth of the plants. The ET depth is estimated using the neutron probe data (Appendix A). Moisture infiltrates unless it is transpired or evaporated. Moisture that is not consumed by evapotranspiration continues through the soil profile into the basalt and eventually to the aquifer. This occurs generally within the first few feet of the land surface. All moisture passing lower than the ET depth is considered to eventually reach the aquifer. However, changes in storage, perching lateral movement, entrapment in buried waste, etc., may have a bearing on the water movement.

3.2.1.2 Time Domain Reflectometer Monitoring. The TDR is a nondestructive technique used to measure water content in the soil. The technique is based on measuring the dielectric constant of the soil using the propagation velocity of a pulse as it travels along an electromagnetic transmission line (or probe) buried in the soil (Whalley 1993). The travel time of the pulse yields an "apparent" probe length, which is dependent upon the dielectric properties of the medium surrounding the probe. Because free water has a dielectric constant 20 times that of mineral matter, the dielectric constant of the soil is dominated by the contribution from soil water. The volumetric water content is related empirically to the actual probe length and apparent probe length by the Ledieu Equation (3-1) (Ledieu et al. 1986):

where:

$$\theta_v = 0.1138(L_a / L) - 0.1758 \qquad (3-1)$$

θ_v	=	volumetric water content
L	=	probe length
L_a	=	apparent probe length.

The use of the Ledieu equation to calculate volumetric water content is recommend by the manufacturer, Campbell Scientific of Logan Utah.

The basic components of the TDR soil moisture monitoring system include: (1) the TDR pulse generator/receiver that generates the electromagnetic pulse and provides communications interface with the datalogger, (2) a datalogger that stores reflected signals and calculates moisture contents as well as controlling sampling frequency, (3) multiplexers that allow channel switching and sampling of multiple probes, and (4) the buried coaxial cables and probes that transmit and reflect the electromagnetic pulse. Three-rod, 30-cm (11.8-in.) long probes constructed of stainless steel with heavy gauge RG8 coaxial cable were employed for the cable and probes. The system is powered by a deep cell 12-volt marine battery, which is charged with a solar panel.

The TDR probes and cables were installed in the summer and fall of 1996 at Landfills I and II, following placement of the soil cover (Figure 3-1). A 1.2 × 1.4-m (3.9 × 4.5 ft) trench was dug to the base of the cover and the probes were installed in 15 cm (6-in.) soil lifts, which were compacted to the cover design specifications (Neher 1997). In this way, vertical TDR probe arrays were installed into the cover as shown on Figure 3-2.

The TDR probes were placed at depths of 15, 30, 45, and 60 cm (6, 12, 18, and 24 in.), corresponding to the base of the vegetation layer, center of the compacted layer, base of the compacted layer, and rough grade (Figure 3-2). Each TDR system consists of four vertical arrays located radially north, south, east, and west, approximately 18 m (59 ft) from the central TDR pulse generator and data logging station.

The TDR monitoring for infiltration was initiated in the spring of 1997 following final grading and seeding of the soil cover. The TDR water data analyzed for this report were collected from March 1997 through August 1998. Volumetric moisture content measurements were automatically collected and stored on a datalogger every 12 hours.

Field problems led to data gaps on two occasions. In October 1997 during seeding operations, heavy equipment accidentally ripped up wiring to the datalogger in Landfill II. The system was repaired in January 1998. Therefore, no Landfill II TDR data is available from October 17, 1997 through January 21, 1998. Incorrect rewiring of the TDR in January 1998 continued the data loss until August 1998 at the south TDR array at Landfill II, and the 15-, 30-, and 45-cm (6-, 12-, and 18-in.) depths in the north array at Landfill II.

The TDR arrays were not installed in the cover of Landfill III. Modeling results using the Hydrologic Evaluation of Landfill Performance (HELP) model (Sorenson 1996) indicated that infiltration through the cover and existing material of Landfill III would be approximately two orders of

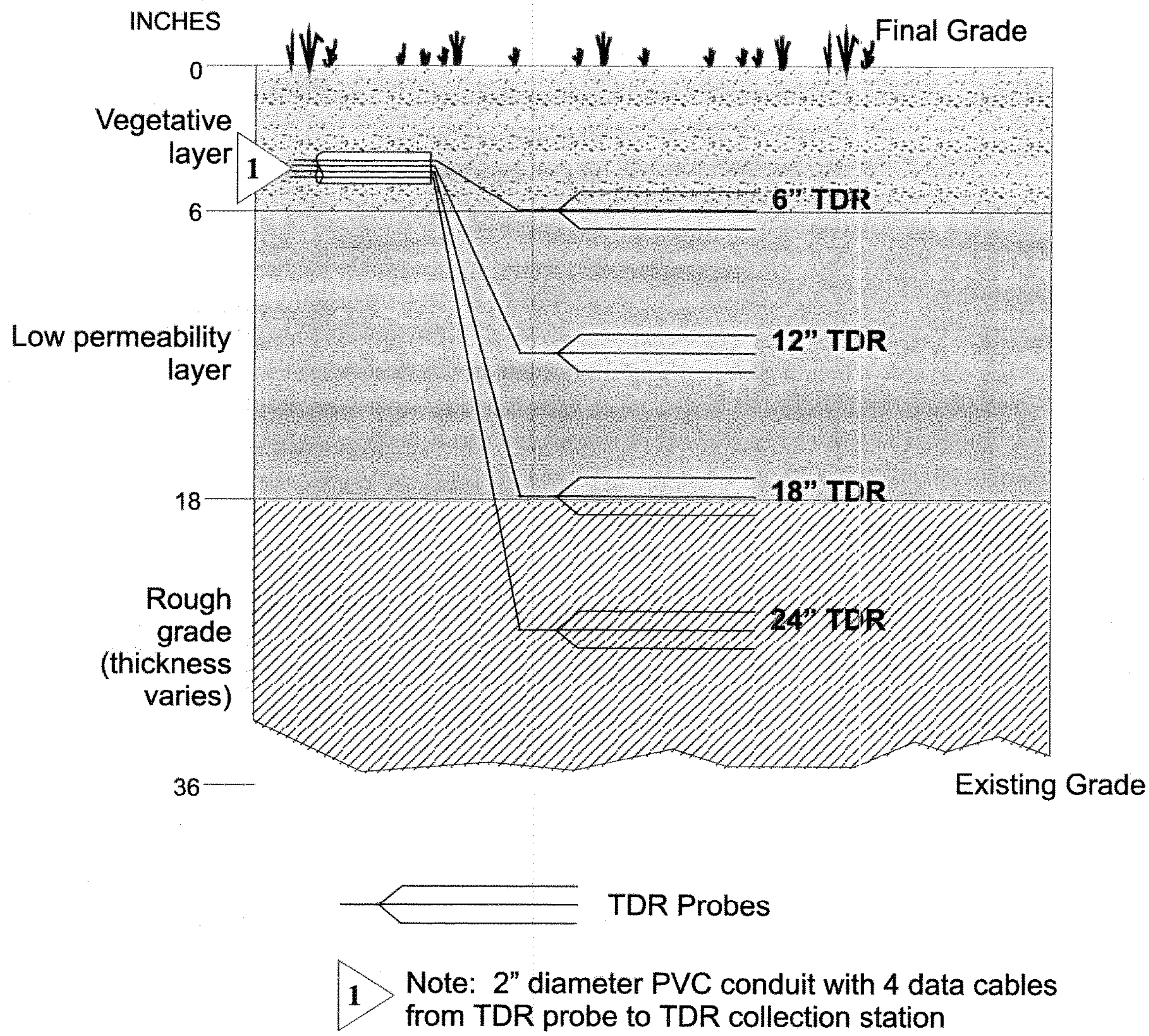

Figure 3-2. The TDR probe configuration for monitoring in the landfill covers.

magnitude less than through Landfill I, and one order of magnitude less than through Landfill II. Because of the greatly reduced infiltration expectations due to the shorter runoff distance, installation of a TDR array on Landfill III was not considered necessary.

The TDR arrays at Landfills I and II were instrumented to collect soil temperature in November 1998. Prior to this time the TDR arrays were not equipped to monitor the soil water freeze/thaw cycle. Therefore, soil temperature data from the Engineered Barrier Test Facility (EBTF) outside the Radioactive Waste Management Complex (RWMC) has been applied to the CFA landfills TDR data (Lockheed Martin Idaho Technologies Company [INEEL] 1998a). However, there are limitations to applying the EBTF soil temperature data to the CFA landfill cover TDR monitoring. First, the EBTF is located approximately 9 km (6 mi) from CFA Landfill I. Secondly, the EBTF is an above-ground-level facility. The test plots have concrete sides, earthen berms surround the facility, and an access trench along one side of each plot is heated in the winter. The significant differences in location and construction limit the confidence with which the CFA soil moisture data can be interpreted using the EBTF soil-temperature data. However, the EBTF soil-temperature data can provide a frame of reference for soil freeze/thaw cycles.

3.2.2 Soil Gas Monitoring

Five soil gas sampling boreholes were installed near the CFA landfills to monitor for soil gases and contaminants (see Figure 3-3). One borehole was installed adjacent to Landfill I; two adjacent to Landfill III (one of which is proximal to Landfill I); and two adjacent to Landfill II. Each borehole was completed with four soil gas sampling ports: two above the shallow interbed and two below. The construction of the five soil gas sampling boreholes and vadose zone lithology is in Appendix B.

Gas sampling ports are designed to sample soil gases from discrete depths. The ports are constructed from 0.95-cm (0.375-in.) diameter seamless stainless steel tubing with a 0.9-m (3-ft) perforated section located at the intended depth of soil gas sample collection. One shallow sampling port was placed within the surficial sediments. One deep sampling port was placed in basalt above the shallow interbed, which is approximately 12 to 18 m (40 to 60 ft) below land surface. Two deep sampling ports were placed below the shallow interbed with perforated sections vertically separated by approximately 9 m (30 ft). The perforated sections of the deep sampling ports were located adjacent to fracture zones in the basalt to place the sampling location adjacent to the most probable avenue of soil gas migration.

All ports are surrounded with silica sand and separated by grout seals. The amount of vapor equal to the calculated purge volume of the tubing is extracted from the sampling port using a vacuum pump. The gas sample is collected in a sumi canister, which is sent to the laboratory for analysis of the gas. All five sampling ports were sampled on the same days. The samples were analyzed for VOCs including methane.

3.2.3 Quality Assurance/Quality Control Sampling

This section presents a discussion of the precision and accuracy associated with the data collected during the 2-year intensive monitoring program. The contribution of measurement error to the total error is assessed in this section. Analytical data from quality control samples was used to estimate accuracy and precision and to make quantitative estimates of measurement error and bias.

3.2.3.1 Overall Precision. Precision is a measure of the reproducibility of measurements under a given set of conditions. Precision is affected by sample collection procedures at the site and the natural

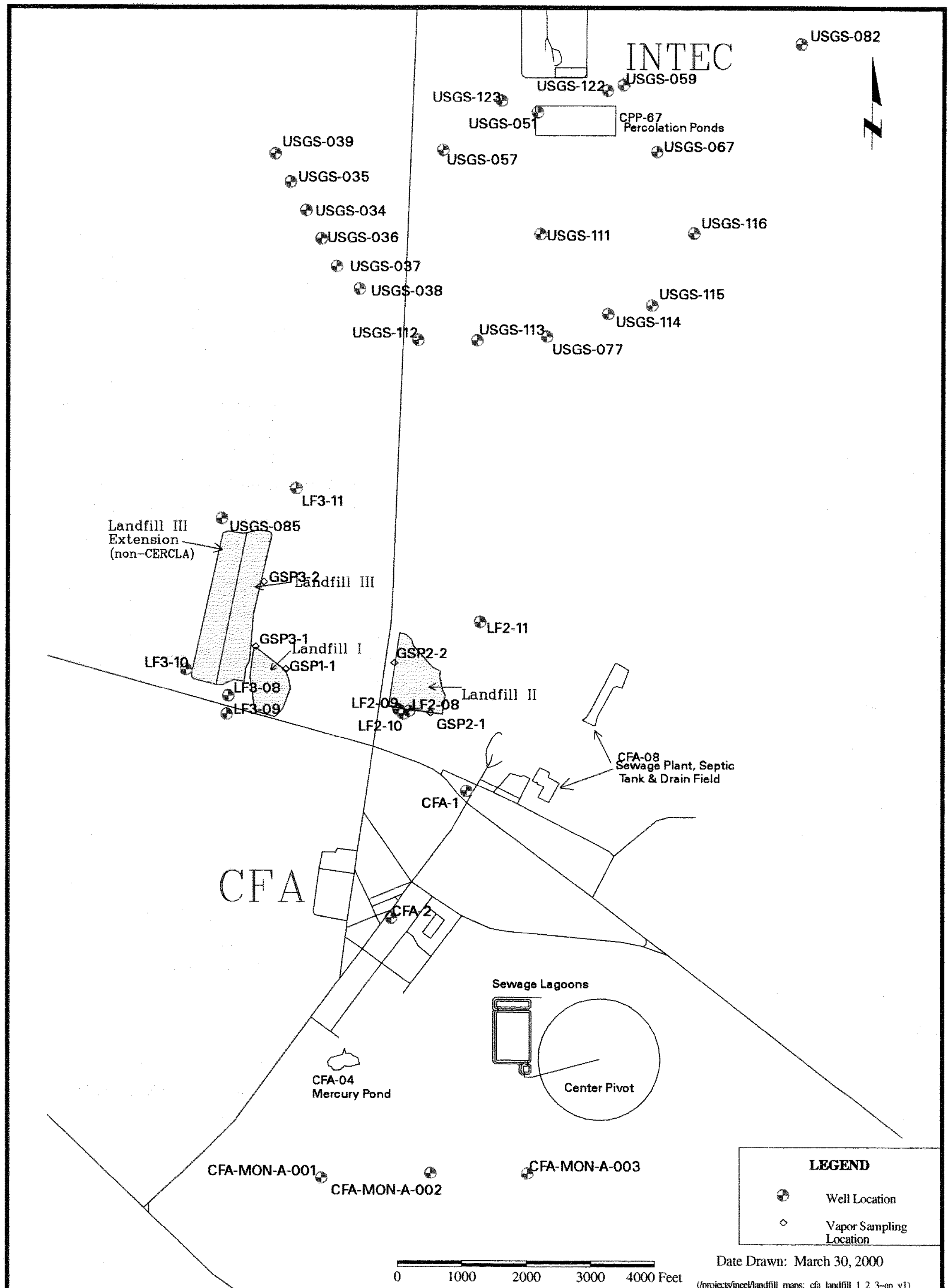

Figure 3-3. Vapor Sampling Locations and Groundwater Monitoring Wells.

heterogenity of the sampling media. Duplicate samples were collected for groundwater and soil gas samples at the CFA landfills. The relative percent difference (RPD) was calculated for each duplicate pair that had true values for both the initial sample and the field duplicate.

The RPDs for many analytes were less than 20% for the majority of the groundwater duplicates (Table 3-1). However, for duplicate pairs close to the detection limit the RPD was frequently much higher than 20% and was due to the large error associated with analytes detected at concentrations near the detection limit. Examples of metals with duplicate pairs at concentrations near the detection limit include mercury, arsenic, barium, and vanadium.

For soil gas analytes, dichlorodifluoromethane, trichloroethene, and tetrachloroethene were detected in field blanks indicating that contamination problems in the field or at the laboratory may also be responsible for the anomalously high RPDs at concentrations near the detection for a few soil gas duplicates samples.

3.2.3.2 Overall Accuracy. Accuracy is a measure of bias expressed as the difference between the measured value and the true value in a measurement system. Accuracy is affected by the methods used for sample preservation, sample handling, field contamination, the sample matrix, and equipment calibration. The effects of the first three parameters are assessed through evaluating the field and equipment blank data. The presence of a contaminant in the field blank or trip blank reveals that cross-contamination may have occurred.

Laboratory accuracy is assured through the use of standard methods with calibration standards that are traceable to the National Institute of Standards and Technology. The laboratory precision and accuracy requirements are part of the validation criteria against which laboratory data are evaluated. Laboratory precision is estimated through the use of spiked samples and/or laboratory control samples. The number of laboratory quality control (QC) samples are specified in the analytical methods used in the INEEL Sample Management Office statement of work or task order.

Overall, the accuracy of the samples is acceptable based on data validation results. Split samples were not taken, but other QA/QC samples were acceptable (see Section 3.2.3.1). The accuracy of some of the measurements is questionable because many of the analytes were also present in an associated blank sample. For example, beryllium, selenium, and cadmium were detected at concentrations near the detection limit and also occurred in the corresponding laboratory blank suggesting that those detections are questionable. For analytes detected near the detection limit, the accuracy is marginal with the sample results biased to the high side. This marginal accuracy only affects the data reporting if the results are close to regulatory limits. For analytes such as sulfate and potassium, the occurrence of these analytes in the laboratory blanks usually does not affect the data because the blank concentrations are orders of magnitude less than the sample concentrations.

3.2.3.3 Completeness. Completeness is a measure of the quantity of usable data collected during an investigation. The completeness goal includes field sample completeness (factors such as equipment and instrument malfunctions and insufficient recovery) and analytical completeness, which includes factors such as damage during sample handling, shipping, packing, and storage. The monitoring plan requires an overall completeness goal of 90% for this project (DOE-ID 1997a).

Table 3-1. Quality assurance/quality control summary of groundwater and soil gas analytes.

Well	Compound Name	Units	Minimum RPD	Maximum RPD	Number of Dups[a]	Percent Complete[b]
Groundwater Analytes						
	Organic Analytes					
	1,1,1-Trichloroethane	µg/L			0	100
	1,2,4-Trimethylbenzene	µg/L			0	100
	1,2-Dichloroethane	µg/L			0	100
	1,3,5-Trimethylbenzene	µg/L			0	100
	Toluene	µg/L			0	100
	Xylene (total)	µg/L			0	100
	Carbon Tetrachloride	µg/L			0	100
	Ethylbenzene	µg/L			0	100
	Bromomethane	µg/L			0	95.5
All other organic analytes except acetone, 2-butanone, 2-hexanone[c]						100
	Inorganic Analytes					
	Alkalinity	g/L		0.8	1	100
	Alkalinity (Total)	mg/L	10.2	14.4	2	100
	Alkalinity-Bicarbonate	mg/L	10.2	14.4	2	100
	Aluminum	µg/L	11	139[d]	4	100
	Arsenic	µg/L	0	100[d]	7	88.6
	Barium	µg/L	0	138.5	7	100
	Beryllium	µg/L			0	76
	Cadmium	µg/L			0	76
	Calcium	µg/L	0.5	3	7	10
	Chloride	mg/L	0	1.1	3	100
	Chromium	µg/L	9.2	15.4	3	100
	Cobalt	µg/L			0	100
	Copper	µg/L			0	100
	Fluoride	mg/L	0	15.4	3	100
	Iron	µg/L	17.4	47.6	4	89.8
	Lead	µg/L	0	35.9[d]	5	88.6
	Magnesium	µg/L	0.6	16.7	7	100

Table 3-1. (continued).

Well	Compound Name	Units	Minimum RPD	Maximum RPD	Number of Dups[a]	Percent Complete[b]
	Manganese	µg/L	6.5	41.7[d]	6	100
	Mercury	µg/L		136.4[d]	1	100
	Nickel	µg/L		25.0	1	100
	Nitrate/Nitrite	mg-N/L	0	4.7	3	87.5
	Potassium	µg/L	2	11.3	7	100
	Silver	µg/L			0	87.5
	Selenium	µg/L		7.4	1	78.4
	Sodium	µg/L	0.7	2.3	7	100
	Sulfate	mg/L	4.5	11.6	3	100
	Thallium	µg/L			0	76.1
	Vanadium	µg/L	26.8	163.6[d]	2	100
	Zinc	µg/L	2.7	36.9	6	100
Soil Gas Analytes						
	1,1,1-Trichloroethane	µg/L	0	80	7	100
	Trichlorofluoromethane	µg/L	0	51.9	7	100
	Trichloroethene	µg/L	2.2	138.2	6	100
	Trans-1,1-Dichloroethene	µg/L		13.3	1	100
	Tetrachloroethene	µg/L	1.6	121.7	5	100
	Methylene Chloride	µg/L	0	10.5	2	100
	Methane	µg/L	3.6	48.1	6	100
	Dichlorodifluoromethane	µg/L	0	114.6	6	100
	Chloromethane	µg/L			0	100
	Chloroform	µg/L	0	26.4	4	100
	Chloroethane	µg/L	15.4	24.6	3	100
	Carbon Tetrachloride	µg/L	2.6	58.8	2	100
	Benzene	µg/L		28.6	1	100
	Acetone	µg/L		11.8	1	100
	1,2-Dichloropropane	µg/L		50	1	100
	1,2-Dichloroethane	µg/L	0	13.3	2	100
	1,1-Dichloroethene	µg/L	1.7	99.3	6	100
	1,1-Dichloroethene	µg/L	0	51.4	6	100

Table 3-1. (continued).

Well	Compound Name	Units	Minimum RPD	Maximum RPD	Number of Dups[a]	Percent Complete[b]
All other soil gas analytes					0	
Overall completeness						
Groundwater						
	Volatile Organic Compounds					100
	Metals					92
Soil Gas Analyses						100

a. Analyte must be detected in both the sample and the dup for a RPD to be calculated. A zero in this column indicates that there are no duplicate pairs in which the analyte was detected in both the sample and the duplicate.

b. Percent complete is the total samples minus the rejected samples divided by the total samples.

c. Acetone, 2-hexanone, and 2-butanone are common laboratory contaminants.

d. The high RPD is due to duplicate pairs close to the detection limit.

For the groundwater sampling, eleven wells were sampled quarterly for 2 years and five soil gas probe locations, consisting of four sampling depths and each were sampled semi-annually. The completeness for the various parameters is summarized in Table 3-1. The completeness for the soil gas analytes was 100%. The overall completeness for the VOCs in groundwater was 100%. The completeness was less than 100% for a couple of the common laboratory contaminants such as acetone, 2-butanone, and 2-hexanone. The overall completeness for metals was 92% (Table 3-1). Completeness for the individual metals ranged from 76% for beryllium, cadmium, and thallium to 100% for several metals.

3.2.3.4 Comparability and Representativeness. Comparability is a qualitative characteristic that refers to the confidence with which one data set can be compared to another. As a minimum, comparable data must be obtained using unbiased sample designs. If sampling designs are not unbiased, the reasons for selecting another design should be well documented. Representativeness is a qualitative parameter that expresses the degree to which the sampling and analysis data reflect the characteristics being measured. The representativeness criterion is best satisfied by confirming that sampling locations are selected properly and a sufficient number of samples are collected to meet the confidence level required by the intended use of the data.

Data comparability was ensured through the use of standard sample collection techniques, the *Quality Assurance Project Plan for Waste Area Groups 1, 2, 3, 4, 5, 6, 7, 10, and Inactive Sites* (DOE-ID 1997b), the use of field QC samples, and the use of standard analytical methods by the laboratories. The data collected for each well are intended to supplement existing monitoring well data in support of the remedial action. The above items ensure that the data collected are representative of the aquifer and soil gas.

3.2.3.5 Quality Control and Quality Assurance for the NAT and TDR Data. A description of the neutron probe calibration and water volumetric calculations are provided in Appendix A. The measuring technique, accuracy, and data collection methods for the neutron probe measurements are described in Section 3.2.1.1. TDR volumetric water content determination was discussed in Section 3.2.1.2.

3.2.4 Groundwater Monitoring

Water-level measurements were taken from 27 monitoring wells and 11 monitoring wells were sampled for eight quarters (Figure 3-3). Depth-to-water measurements were used to determine water-level elevations, groundwater flow direction, and groundwater gradients. The groundwater sampling was used to establish baseline levels to determine the potential impacts of landfill leachate.

3.2.4.1 Water-level Data. Water-level measurements for 27 aquifer wells at or near the CFA were collected monthly from between May 1996 and October 1998. An electric water-level indicator was used to measure water levels. The aquifer beneath the CFA is assumed to be unconfined or only partially confined and, as such, the water levels measured in these aquifer wells are collectively referred to as the water table.

3.2.4.2 Aquifer Wells Included in Water-level Monitoring. The 27 aquifer wells were included in the water-level measurement program and well construction details are included in Table 3-2. The 27 wells are located near the CFA landfills, downgradient of the CFA facilities, and north of CFA at locations south of the INTEC and the TRA. A map showing the well locations relative to the CFA is depicted in Figure 3-3. Monitoring wells in the immediate vicinity of the landfills were Wells LF 2-08 through LF 2-11 and LF 3-08 through LF 3-10 (Figure 3-3). Additional monitoring wells upgradient of the CFA landfills included USGS 20, 34 through 39, 57, 77, 82, 85, and 111 through 116 (Figure 3-3). The three additional wells downgradient of the CFA were CFA-MON-001, CFA-MON-002, and CFA-MON-003.

Although LF 2-12 and LF 3-11 also are in the vicinity, they were abandoned before monitoring began (Neher 1997). Wells LF 2-12 and LF 3-11, which were used during the remedial investigation of the CFA landfills, are obstructed due to pumps that have become lodged inside of the well casings. Repeated attempts to remove the obstructions were unsuccessful. In both wells, the obstructions are in the casing above the water table and neither well can be sampled.

3.2.4.3 Water-level Data Uncertainty. The uncertainty associated with water level measurements results from several contributing factors: human error reading the electric line graduations, electric line stretch, deviations in survey equipment accuracy, and measuring point inaccuracies (Table 3-3). However, borehole deviation is probably the largest uncertainty for water level measurement (Table 3-3). Total uncertainty estimates assume the various uncertainty contributions can be summed (Table 3-4).

The estimated error for the set of 27 wells ranges from 0.036 m (0.12 ft) for the simplest, least-deviated wells to 0.356 m (0.84 ft) for LF 2-09, a highly deviated well with some measuring-point discrepancy (Table 3-4). The average estimated water-level error for these 27 wells is 0.085 m (0.28 ft). Due to its water-level access restrictions, LF 2-10 may not yield reliable water-level measurements.

3.2.4.4 Groundwater Sampling. Groundwater samples were collected from 11 wells in the vicinity of the CFA for organic (VOCs) and inorganic (metals, anions, and alkalinity) analytes. Quarterly monitoring started in 1996 and 2 years of monitoring data were obtained for the wells. The composition of major ions (calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulfate, and nitrate) was used to characterize groundwater flow paths and to evaluate groundwater quality. Analysis of organic compounds and trace metals was used to establish baseline concentrations for those constituents.

Table 3-2. Groundwater well construction details as depths below land surface.

Well Name	Northing[a] (ft)	Easting (ft)	Land Surface Elevation[b]	Borehole Depth[b]	Borehole Elevation[b]	Completed Depth[b]	Completed Elevation[b]	Open Interval Depths[b]	Open Interval Elevations[b]	Total Open Interval (ft)
CFA-MON-A-001	675,528.0	293,001.6	4,936.4	547	4,389	527	4,409	519–527	4,417–4,409	8
CFA-MON-A-002	675,602.3	294,701.0	4,932.2	526	4,406	522	4,410	519–526	4,413–4,406	7
CFA-MON-A-003	675,593.8	296,205.2	4,930.3	515	4,415	510.9	4,419	491–511	4,439–4,419	20
LF2-08	682,878.8	294,362.3	4,931.7	526	4,406	526	4,406	485–495	4,447–4,437	10
LF2-09	682,898.6	294,194.7	4,932.2	676	4,256	497	4,435	470–497	4,463–4,435	27
LF2-10	682,831.1	294,274.5	4,932.5	816	4,117	766	4,167	725–735, 745–765	4,208–4,198, 4,188–4,168	30
LF2-11	684,292.0	295,463.3	4,928.4	510.9	4,418	499	4,429	466–499	4,462–4,429	33
LF3-08	683,111.6	291,544.2	4,940.2	526	4,414	510	4,430	500–510	4,440–4,430	10
LF3-09	682,824.8	291,517.9	4,941.1	517	4,424	500	4,441	480–500	4,461–4,441	20
LF3-10	683,530.3	290,879.7	4,942.6	530	4,413	501	4,442	481–501	4,462–4,442	20
USGS-020	686,506.2	301,200.3	4,916.4	676	4,240	676	4,240	467–477, 515–552	4,449–4,439, 4,401–4,364	47
USGS-034	690,801.5	292,743.6	4,929.2	700	4,229	699.9	4,229	500–578	4,429–4,351	78
USGS-035	691,252.9	292,499.2	4,929.6	578.5	4,351	578.5	4,351	143–579	4,787–4,351	436
USGS-036	690,360.4	292,981.8	4,929.2	567.1	4,362	567.1	4,362	430–567	4,499–4,362	137
USGS-037	689,922.4	293,223.3	4,929.4	571.5	4,358	571.5	4,358	507–572	4,422–4,358	64.5
USGS-038	689,568.6	293,579.3	4,929.6	729	4,201	724	4,206	678–729	4,252–4,201	51
USGS-039	691,692.4	292,261.2	4,930.9	572	4,359	571.9	4,359	48–493, 507–572	4,883–4,438, 4,424–4,359	510
USGS-057	691,753.3	294,871.2	4,922.5	732	4,191	732	4,191	474–732	4,449–4,191	258
USGS-077	688,823.2	296,495.2	4,921.8	610	4,312	610	4,312	470–586	4,452–4,336	116
USGS-082	693,413.2	300,455.6	4,907.0	700	4,207	700	4,207	470–570, 593–693	4,437–4,337, 4,314–4,214	200
USGS-085	685,932.1	291,436.4	4,939.3	637	4,302	637	4,302	522–637	4,417–4,302	115
USGS-111	690,435.3	296,390.9	4,920.5	600	4,321	595	4,326	430–600	4,491–4,321	170
USGS-112	688,766.5	294,492.8	4,927.8	563	4,365	563	4,365	430–563	4,498–4,365	133
USGS-113	688,761.3	295,410.2	4,925.3	564	4,361	564	4,361	443–561	4,482–4,364	118
USGS-114	689,181.8	297,442.0	4,920.1	562.5	4,358	562.5	4,358	440–560	4,480–4,360	120
USGS-115	689,311.3	298,133.1	4,918.8	581	4,338	581	4,338	437–580	4,482–4,339	143
USGS-116	690,453.1	298,786.0	4,916.0	580	4,336	580	4,336	401–572	4,515–4,344	171

a. Northings and Eastings are based on NAD 27 datum (North American Datum 1927).

b. Elevations are in feet above mean sea level, NGVD 29 (National Vertical Geodetic Datum of 1929); depths are in feet below land surface.

Table 3-3. 1993 well deviation survey results.

Well Name	Drill Method	Tool Type Used in Survey	Degrees Deviation	Equipment Error (ft)	First-Order Deviation Correction Formula	Difference (ft) (Corrected/ Uncorrected Water Levels) (June 98)
CFA-MON-A-001	Rotary	NS[a]	NS	NS	4,936.44+2.08-(water depth[b])	0.0
CFA-MON-A-002	Rotary	NS	NS	NS	4,932.24+1.95-wd[a]	0.0
CFA-MON-A-003	Rotary	NS	NS	NS	4,930.31+1.62-wd	0.0
LF2-08	Rotary	Low	9.0	0.11	4,933.14-[- 1.36+(0.9966667*wd)]	2.7
LF2-09	Rotary	High	12.0	0.42	4,933.46-[2.99+(0.9817*wd)]	5.8
LF2-10	Rotary	Low	10.0	0.11	4,933.86-[1.08+(0.9962* wd)]	0.5
LF2-11	Rotary	Low	2.0	0.11	4,930.17-[-0.01+(wd)]	0.0
LF3-08	Rotary	High	2.0	0.42	4,941.84-[9.7+(0.97* wd)]	4.7
LF3-09	Hammer	Low	14.0	0.11	4,942.77-(-0.13+ wd)	0.1
LF3-10	Hammer	Low	2.5	0.11	4,944.62-(-0.01+ wd)	0.0
USGS-020	Cable tool	Low	2.0	0.11	4,917.07-[0.14+(0.9996* wd)]	0.0
USGS-034	Cable tool	Low	2.0	0.11	4,930.27-[0.21+(0.9994* wd)]	0.1
USGS-035	Cable tool	Low	3.0	0.11	4,931.2-[-0.13+(0.9967* wd)]	1.7
USGS-036	Cable tool	Low	1.0	0.11	4,930.43-(-0.05+ wd)	0.1
USGS-037	Cable tool	Low	0.0	0.11	4,930.61- wd	0.0
USGS-038	Cable tool	Low	1.0	0.11	4,931.06-(-0.06+ wd)	0.1
USGS-039	Cable tool	Low	2.0	0.11	4,932.18-[0.21+(0.9993* wd)]	0.1
USGS-057	Cable tool	Low	1.0	0.11	4,924.44-[0.05+(0.9998* wd)]	0.0
USGS-077	Cable tool	Low	0.5	0.11	4,924.01-(-0.01+ wd)	0.0
USGS-082	Cable tool	Low	2.0	0.11	4,908.6-(0.075+ wd)	-0.1
USGS-085	Cable tool	NS	NS	NS	4,941.52- wd	0.0
USGS-111	Rotary	High	16.0	0.42	4,922.75-[12.83+(0.9614* wd)]	5.4
USGS-112	Rotary	Low	11.0	0.11	[4,930.13-[4.56+(0.9848* wd)]	2.7
USGS-113	Rotary	High	15.0	0.42	4,927.67-[6.9+(0.9724* wd)]	6.2
USGS-114	Rotary	High	12.0	0.42	4,922.34-[5.47+(0.9782* wd)]	4.8
USGS-115	Rotary	Low	10.5	0.11	4,921.13-[5.47+(0.9834* wd)]	2.3
USGS-116	Rotary	Low	5.0	0.11	4,918.6-[0.9+(0.9976* wd)]	0.2

a. NS = well was not surveyed for deviation in 1993.

b. Water depth is measured depth to water below measuring point (wd = water depth).

Table 3-4. Estimates of total error associated with water level measurements.

Well Name	Indicator Line Stretch (ft)	Indicator Line Read Error (ft)	Deviation Correction Error (ft)	Measuring Point Error (ft)	Estimated Total Error (ft)
CFA-MON-A-001	0.1	0.02	0	0	0.12
CFA-MON-A-002	0.1	0.02	0	0	0.12
CFA-MON-A-003	0.1	0.02	0	0	0.12
LF2-08	0.1	0.02	0.11	0	0.23
LF2-09	0.1	0.02	0.42	0.3	0.84
LF2-10	0.1	0.02	0.11	0	0.23
LF2-11	0.1	0.02	0.11	0.4	0.63
LF3-08	0.1	0.02	0.42	0	0.54
LF3-09	0.1	0.02	0.11	0.3	0.53
LF3-10	0.1	0.02	0.11	0.2	0.43
USGS-020	0.1	0.02	0	0	0.12
USGS-034	0.1	0.02	0	0	0.12
USGS-035	0.1	0.02	0	0	0.12
USGS-036	0.1	0.02	0	0.1	0.22
USGS-037	0.1	0.02	0	0	0.12
USGS-038	0.1	0.02	0	0.1	0.22
USGS-039	0.1	0.02	0	0	0.12
USGS-057	0.1	0.02	0	0	0.12
USGS-077	0.1	0.02	0	0	0.12
USGS-082	0.1	0.02	0	0	0.12
USGS-085	0.1	0.02	0	0	0.12
USGS-111	0.1	0.02	0.42	0	0.54
USGS-112	0.1	0.02	0.11	0	0.23
USGS-113	0.1	0.02	0.42	0	0.54

4. MONITORING RESULTS AND INTERPRETATION

This section presents the results of infiltration, soil gas, and groundwater monitoring at CFA Landfills I, II, and III. The infiltration monitoring utilized TDR and neutron-probe data to evaluate infiltration. Soil gas monitoring was conducted to determine if contaminants are present in the vadose zone. The groundwater monitoring consisted of water-level measurements and groundwater sampling and analysis.

4.1 Infiltration Monitoring

The objective of infiltration monitoring at the CFA landfills was to document the effectiveness of the landfill covers for minimizing infiltration into the landfill wastes (Neher 1997). In the Post-ROD monitoring plan (Neher 1997) for the CFA landfills, a performance criterion was to be established following the 2-year intensive monitoring phase. A TDR system was installed in the native soil cover at Landfills I and II during the remedial action. Existing neutron-probe access tubes were utilized for moisture measurements.

Water that moves into the soil is defined as "infiltration." Water that moves below the ET depth is termed "recharge." Infiltration and recharge are represented by an increase in water storage within a system. In addition to recharge, evapotranspiration (ET) is a large contributor to decreasing storage in near surface soils, moving water upward and out of the soil. The term "drainage" refers to water movement out of a unit thickness of soil or a decrease in soil moisture content, but does not indicate the direction of movement. The ET depth depends on the plants and their rooting depths, soil types, and the meteorological conditions that are present. The ET depth was evaluated to be 1.07 to 1.22 m (3.5 to 4 ft) and is evaluated in Appendix A.

4.1.1 Neutron Probe Monitoring Data

The volume of water infiltrating past the ET depth or rooting depth is the target for the neutron probe monitoring of the NATs. Water that passes through the ET depth may pick up contaminants in the landfill waste and carry them to the groundwater. The volumes for infiltration, drainage, and recharge have been calculated for the landfill NATs. A 1-year cycle from August 1997 through August 1998 was chosen for drainage analysis because it is the only complete year of data. During this one year period, a total of 9.53 inches of precipitation was recorded. The timing of the precipitation is given in Appendix A. A list of the neutron probe measurements and infiltration, recharge, and drainage calculations are included in Appendix A.

4.1.1.1 Neutron Probe Data Interpretation. Neutron probe logs for each NAT show large fluctuations through time in the upper section, which are caused by annual precipitation cycles. Counts below the ET depth change very little through time (see Figures C-1 through C-4 in Appendix C). Three-dimensional plots of the difference in counts from month to month show an obvious ridge in all of the charts (except LF 3-05) along the April axis at all depths. This is evidence of "wetting up" of the entire monitored soil profile in April 1998 (see Figures C-6 through C-10). Infiltration through the 0.6 m (2-ft) native soil cover was observed at LF2-07, but infiltration at LF3-05 was not as noticeable. The undulating floor in the charts may reflect neutron data precision.

The high peak in counts at 2 m (8 ft.) in LF2-07 may be a response to materials in the landfill waste, as the NAT was driven directly through waste. This peak has been evident since initial monitoring in 1988 (Figure C-3).

The timing of the moisture increases in the soil suggests that snow melt probably accounts for most of the infiltration at the landfills. The largest monitored increase in counts occurred on March 2, 1997 and April 9, 1998. The large count increase indicates infiltration occurred on or before those dates. Previous studies of the NATs data (Ansley et al. 1988 and Keck, et al. 1995) concluded snowmelt was a major contributor to infiltration at the landfills. This appears to be true for 1998 data. Snow depth data at the CFA National Oceanic and Atmospheric Administration (NOAA) station show more snow on the ground in 1998 than in 1997. Accordingly, the infiltration in April of 1998 was more extensive than in 1997 and reached the total depth of the NATs at four out of the five NAT locations (LF2-07, LF2-03, LF2-04, and LF3-03). Only LF3-05 did not show infiltration to the total depth of the NAT in 1998.

Neutron-probe access tube LF2-07 is located between the north and east TDR arrays at Landfill II and is the only NAT located near the TDR arrays. The TDR data from Landfill II indicate infiltration to the 0.6 m (2-ft) depth occurred on March 25 at the north array and on March 15 at the east array. The increase in neutron moisture probe counts shown on April 9, 1998 occurred between the March 11 and April 9 monitoring dates. While the timing of infiltration at NAT LF2-07 is in general agreement with the TDR data, infiltration and drainage may have occurred during the month long data gap between NAT monitoring events. This points out the need for more frequent monitoring of the NATs during the late winter and spring.

4.1.1.2 Infiltration and Recharge Estimates Using NAT Data. The amount of infiltration and recharge was estimated by two methods. The calculations of moisture contents and volumetric water contents are described in Appendix A. Methods for estimating infiltration and recharge are described in Appendix A. An evaluation of the evapotranspiration depth is also given in Appendix A.

Estimates of water movement were made based on assumptions, and as such are approximations of infiltration, recharge, and drainage values (Table 4-1). The principal limitation is that measurements were taken monthly at the NAT locations and some infiltration may have been missed by not monitoring often enough during the late winter and spring.

Recharge estimates for the spring of 1998 were estimated using two different methods. The first method estimated recharge by calculating the change in water storage based on the calibration equations. The second method was to use a water balance approach that partitioned the available precipitation (8.53 cm or 3.36 inches) based on the change in neutron probe counts, to the ET zone, or below the ET depth (see Appendix A). No calibration equation was used for the water balance estimate. Both methods are described in detail in Appendix A. Based on the change in storage using the calibration calculations (first method), the estimates of recharge for 1998 range from 0.28 cm (0.11 in.) at LF3-05 to 6.17 cm (2.43 in.) at LF2-03. The water balance method yields estimates from 0.41 cm (0.16 in.) for LF3-05 to 6.53 cm (2.57 in.) for LF2-04. Both methods yield similar recharge estimates as shown in Table 4-1.

The data from the spring of 1997 suggest that a distinct recharge event was absent or occurred at much lower levels than in 1998. A recharge event appears to take place in the middle of January at LF3-03. The January recharge event is less defined at the other NAT locations.

The neutron probe data indicate that recharge probably varies considerably from year to year. The data for 1997 and 1998 suggest considerable difference in recharge estimates. In some years, recharge may be very low or non-existent, as was found in Ansley et al. (1988). The key events that appear to enhance infiltration are sudden snowmelt and greater than average precipitation. The sudden snow melt event in 1998 is probably responsible for the much greater infiltration and recharge in 1998 than in 1997.

Table 4-1. Summary of NAT data results.

	Neutron Probe Location				
	LF2-03	LF2-04	LF2-07	LF3-03	LF3-05
ET Depth in feet below ground surface	4	4	4	3.5	4
Spring 1998 Infiltration event					
Infiltration	3.23	2.25	3.64	3.21	1.13
Recharge	2.43	1.96	2.27	1.84	0.11
Water Balance of Spring 1998 Infiltration Event					
Infiltration[a]	3.36	3.36	3.36	3.36	3.36
Recharge	2.46	2.57	1.75	2.19	0.16
August 1997 to August 1998 Yearly Drainage					
Total Drainage	6.28	5.79	7.48	6.96	6.36
Drainage Below ET Zone	2.63	2.80	3.08	2.45	2.17
1997 Winter/Spring					
Recharge	0.33[b]	<0.5[c]	<0.5[c]	1.03	0.63
Change in Storage from August 1997 to August 1998					
Total	0.52	0.12	-0.03	-0.45	-1.04
Within Cap	--	--	-0.37	--	-0.41
Within ET Zone	-0.52	-0.12	-0.32	-0.55	-0.60
Below ET Zone	1.04	0.24	0.29	0.10	-0.43

a. The infiltration was set at 3.36 inches based on the available precipitation.

b. These estimates are within the instrument error range for the neutron probe.

c. A recharge event was not identified based on the available data.

4.1.1.3 Drainage Estimates Using NAT Data. Drainage was calculated for the period of August 1997 to August 1998. Drainage estimates were made by calculating the change in storage for each 0.3 m (1 ft) layer over the course of one year and then summing the negative changes in storage (see Appendix A). The total drainage varied from 5.79 in for LF2-04 to 7.48 in for LF2-07. The drainage below the ET zone varied from 5.51 cm (2.17 in.) for LF3-05 to 7.82 cm (3.08 in.) for LF2-07 (Table 4-1).

Although LF3-05 indicated that drainage occurred below 1.21 m (4 ft) in 1998, no recharge was evident in 1998. This lack of recharge correlates with losses from storage that occurred during the period and suggests that the drainage reflects losses in storage that occurred over the year (Table 4-1). In contrast, location LF2-03 had 6.17 cm (2.43 in.) of recharge and 6.08 cm (2.63in.) of drainage below the ET depth, showing that recharge nearly equaled drainage below the ET depth for this NAT located off Landfill II.

4.1.1.4 Water Storage Analysis.

Changes in storage refer to changes in soil moisture content over a period of time that represents a full moisture cycle that is typically a 1-year period. Changes in storage for the two landfill NATs, LF2-07 and LF3-05, for the period of August 1997 to August 1998 indicate that the covers and the entire soil column over the length of the NATs are decreasing in moisture content. The change in water storage indicates that moisture contents are decreasing within the cap and within the ET zone. At LF3-05, moisture content is also decreasing below the ET depth. In contrast, two NATs, LF2-03 and LF2-04, located near Landfill II show increases in total storage, but decreases in storage within the ET zone (Table 4-1). LF3-03 located on the edge of Landfill III also showed a negative change in total water storage.

The negative changes in storage at LF3-05, and to a lesser extent at LF2-07, suggest that the covers are reducing the amount of infiltration and continued drainage is drying the soil column compared to pre-cover conditions.

4.1.2 TDR Monitoring Data

The TDR data for Landfills I and II are shown in Figures C-11 and C-13. The plots show the volumetric moisture content for the 15-, 30-, 45-, and 60-cm (6-, 12-, 18-, and 24-in.) depths. In general, the TDR data show a rapid increase in moisture content at each monitored depth during the spring of 1997 and 1998. The moisture content begins tapering off by mid-July. At most array locations, TDR data indicate much higher moisture content within or at the base of the low-permeability layer (30 and 45 cm [12 and 18 in.]) than above (15 cm [6 in.]) or below (60 cm [24 in.]) the layer.

4.1.2.1 Infiltration through the Soil Cover Based on TDR Data.

The presence or absence of infiltration through the soil cover is the primary concern of the TDR monitoring at Landfills I and II. The low permeability layer of the soil cover is located 15 to 45 cm (6 to 18 in.) below land surface. Moisture contents that increase and decrease within the low permeability layer indicate the movement of water into and out of this compacted layer. Downward water movement through the low permeability layer can be determined by examining TDR moisture content data at the 60-cm (24-in.) depth. Increasing moisture contents at the 60-cm (24-in.) depth indicate water moved vertically through the low permeability layer. The change in moisture content at the 60-cm (24-in.) depth is interpreted to be down in winter and early spring when ET conditions are low and up in summer when ET conditions are high.

The TDR data for Landfills I and II, respectively, are shown in Figures C-11 and C-12. The plots show the volumetric moisture content for the 15-, 30-, 45-, and 60-cm (6-, 12-, 18-, and 24-in.) depths at each array from March 1997 through August 1998. Some of the TDR probes exhibit wide variations between measurements that reflect data noisiness rather than true variations in moisture content. For example, measurements from the Landfill II, west array, 45-cm (18-in.) TDR probe show variations of 10% moisture content or more between 12-hour measurements (Figure C-12). The cause of the TDR noise is not known. The data noise can sometimes obscure minor trends in moisture contents. The data used in calculations were not smoothed for this report.

In general, the TDR data show an increase in moisture content, at each monitored depth, during the spring of 1997 and 1998. However, not all increases are due to infiltration. The rapid "apparent" increase in moisture in March 1997 and 1998 is attributed to soil thawing. When soil water freezes, the dielectric constant of water reduces from approximately 80 to 5. The TDR probes then indicate a false decrease in water content, which is consistent with the decrease in the dielectric constant of water when it is frozen. When the soil thaws, the TDR probes reflect the rise in the dielectric constant as ice turns to liquid and a false increase in water content is detected. Because the spring thaw occurs more suddenly than soil freezing in the fall, the spring shift is more pronounced on the moisture content curves.

Soil temperature instrumentation was not installed in the landfill until fall 1998, and thus no soil temperature data are available for the March 1997 to August 1998 monitoring period. In lieu of data from the landfill, soil temperature data from the Engineered Barrier Test Facility (EBTF) outside the RWMC was applied to the CFA Landfill TDR data to help determine the timing and depths of freezing and thawing of the soil. Limitations in applying the EBTF soil temperature data to the CFA Landfills include distance and construction differences. The EBTF is located approximately 9 km (6 mi) from Landfill I, and is an aboveground facility with concrete sided test plots contained within an earthen berm. An access trench, that is heated in the winter, runs the length of the facility along one side of each of the plots. Despite these differences, the EBTF soil temperature data does provide a frame of reference for soil freezing and thaw cycle.

The rapid increase in water content in late March 1997 is attributed to a soil thaw rather than infiltration. Soil temperature data from the EBTF show the soil was frozen to at least the 60 cm (24-in.) depth from mid-January to approximately March 23, 1997, when the thaw was complete at all but one of the EBTF locations. The timing of the EBTF soil thaw (mid March) is consistent with the sharp rise in water contents in March 1997 at Landfills I and II. Additionally, there was neither a build-up of snow on the ground nor a significant precipitation event that would have provided a source for the observed rise in moisture contents in the landfill soil cover until March 31, 1997.

Moisture content increases in April 1997, after the spring thaw, are attributed to infiltration into the soil cover. The TDR data indicate infiltration through the low permeability layer at 30 to 45 cm (12 to 18 in.) to the 60-cm (24-in.) depth occurred at Landfills I and II (Figures C-13 and C-14) in 1997. The largest increase in water content at the 60-cm (24-in.) depth occurred at the south and west arrays of Landfills I and II.

Infiltration through the low-permeability layer also occurred in the spring of 1998. The EBTF soil temperature data (Porro and Keck 1998) indicate the soil froze to the 0.4 m (1.5-ft) depth during the winter of 1997 to 1998, and the soil thaw was complete by the end of March 1998. If the soil at the landfills also did not freeze to the 60-cm (24-in.) depth at Landfills I and II in 1998, then all increases in moisture contents at that depth are due to infiltration. Snow depth data from the CFA weather station show a build-up of snow on the ground beginning in mid-January 1998. Approximately 20 cm (8 in.) of snow melted within 24 hours, on February 29, 1998. Observations at EBTF indicated several centimeters of snow remained on the ground on March 16, 1998 (Porro and Keck 1998). The snow was melting and there was standing water beneath the snow. Most locations at Landfills I and II indicate a major infiltration event in mid-March of 1998 (refer to Figures C-13 to C-14). Although the timing and amount of snow differs among the CFA NOAA station, the EBTF, and the CFA Landfill locations, the snow pack did provide a source for the 1998 spring infiltration through the soil cover. This initial infiltration resulted in moisture content increases at the 30- and 46-cm(12- and 18-in.) depths within the low permeability layer (Figures C-11 and C-12) and resulted in infiltration through the low-permeability layer to the 60 cm (24-in.) depth at seven monitored TDR array locations (Figures C-13 and C-14). No data are available from Landfill II South, because of equipment problems.

After the initial February and March 1998 infiltration, several precipitation events may also have contributed to infiltration through the soil cover. Significant precipitation in the form of rain occurred March 22 to 25, 1998 (1.34 cm [0.53 in.]) and May 9 to May 13, 1998 (3.4 cm [1.35 in.]), as shown in Figure C-15. These precipitation events are strongly reflected at the 15 cm (6-in.) depth but the response at the 60-cm (24-in.) depth varies between array locations (Figures C-13 and C-14). For example, the west TDR array at Landfill II shows a sharp response to the May precipitation event, whereas the east array at Landfill II shows a muted response.

4.1.2.2 Storage Analyses. Infiltration, drainage, and evapotranspiration are related to the changes in storage of water in the soil profile. The change in storage is represented by the Equation (4-2).

$$\Delta S = I \text{ Water} - D - ET \tag{4-2}$$

where

ΔS = change in storage

I = infiltration

D = drainage out of a system

ET = evapotranspiration.

The infiltration, drainage, and ET out of soil is nearly impossible to measure directly. However, the TDR probes do measure moisture content from which change in storage, ΔS, can be inferred. If the change in storage is positive over time, there is a net gain of water in the soil cover and if the change in storage is negative, there is a net water loss from the soil cover.

Changes in storage were estimated for the lower portion of the soil cover, from 30 to 45 cm (18 to 24 in.) below land surface, which lies directly beneath the low permeability layer. The change in storage, for this lower interval ΔS, was calculated by multiplying the change in moisture content, ΔMC at the 45-cm (24-in.) depth , by the thickness of the soil unit, (L), mathematically expressed as Equation (4-3).

$$\Delta S = \Delta MC \times L \tag{4-3}$$

where

ΔS = change in storage

ΔMC = moisture content

L = soil unit thickness

The change in storage for the lower 15 cm (6-in.) layer was calculated for April through October 1997 and February through August 1998. This encompasses spring infiltration as well as summer ET. The calculations for 1997 used data after the spring thaw in March 1997. All spring measurements were included in the 1998 calculations, because EBTF data suggest the 45 cm (24-in.) depth did not freeze. To calculate the change in moisture content, the minimum and maximum moisture contents were determined for each wetting or drying event. These minimum and maximum moisture contents were then subtracted to yield moisture content changes for each event. Moisture content changes of less than 2% moisture content were not used in the calculations because the variation between data points sometimes overshadowed minor trends. The moisture content changes were multiplied by the 15-cm (6-in.) thickness of the soil layer to calculate the change in storage, ΔS. All the positive ΔSs were added together to calculate the total gain in storage for the 30- to 45-cm (18- to 24-in.) depth, and the negative *ΔSs* were summed to determine the total loss in water storage within the same depth interval.

The changes in storage for a 15-cm (6-in.) soil layer below the low-permeability compacted layer for April through October 1997 and February through August 1998 show gains in storage ranging from 0.30 to 1.3 cm (0.12 in. to 0.54 in.) of water for 1997 and 0.6 to 4.2 cm (0.24 in. to 1.68 in.) for 1998 (Table 4-2). Losses in storage range from 1.06 to 2.1 cm (0.42 in. to 0.84 in.) of water for 1997 and 0.3 to 3.5 cm (0.12 to 1.38 in.) for 1998.

The gains in water storage for both 1997 and 1998 indicate water moved through the low permeability layer and into the 15-cm (6-in.) layer below. The values for 1998 were greater than for 1997, due to the build up of snow during 1998. The decreases in water storage indicate water was lost through either recharge or evapotranspiration. Water lost through recharge would have moved deeper into the landfill sediments or waste, whereas water lost through ET would have moved upward, and out of the system at land surface. The limited instrumentation depth in the landfill cover precludes the ability to differentiate between water loss due to evapotranspiration or water loss due to recharge.

Table 4-2. Changes in water storage within the soil cover, April to October 1997 and February to August 1998.

Array	Change in Storage, 30 to 45 cm (18 to 24 in.) depth			
	1997		1998	
	+ΔS (in.)[a]	-ΔS (in.)	+ΔS (in.)[a]	-ΔS (in.)
Landfill I, North	0.12	-0.84	1.56	-1.08
Landfill I, South	0.30	-0.78	0.54	-0.24
Landfill I, East	0.18	-0.60	0.84	-0.42
Landfill I, West	0.30	-0.78	0.48	-0.12
Landfill II, North	0.18	-0.42	0.24	-0.12
Landfill II, South	0.54	-0.43	—	—
Landfill II, East	NE	-0.48	1.44	-1.02
Landfill II, West	0.30	-0.72	1.68	-1.38

a. A positive ΔS within the 15-cm (6-in.) layer of soil below the compacted, low-permeability layer indicates water moved through the low permeability layer.

— = Data not available for this array.

NE = Not estimated. Data variability obscured minor moisture content increase.

4.1.3 Comparison of TDR and Neutron-Probe Data

The neutron probe data for NAT LF2-07 and the TDR data from Landfill II are compared here for both 1997 and 1998. Because the infiltration for the TDR data was calculated based on a 15 cm (6 in.) thick layer rather than a 0.3 m (1 ft) thick layer for the neutron probe data, the TDR results were doubled in order to be directly comparable to the 0.3 m (1 ft) NAT measurements.

In 1997, the TDR data showed increases of 0.91 to 2.74 cm (0.36 to 1.08 in.) at the 0.6 m (2 ft) depth compared to a 0.40 increase for the 0.6 m (2 ft) depth at LF2-07 from January to March. In 1998, the TDR indicated changes of 1.21 to 8.53 cm (0.48 to 3.36 in.) compared to a 1.12 cm (0.44 in.) increase for the neutron probe from January to April. The above comparisons suggest that the neutron probe infiltration estimates tend to be at the low end of the TDR measurement range.

The TDR data suggests that the neutron probe readings taken on April 9, 1998 should have captured all or the bulk of the spring recharge event. Since the peak TDR moisture content readings are at the beginning of April in 1998, the neutron probe measurement taken on April 9, 1998 should have captured most or all of the moisture infiltrating into the soil column. Water that moved through the soil column rapidly may perch at the soil/basalt contact because of the clay present at that depth. LF3-03 appears to show some perching of water at the soil/basalt contact near the bottom of the tube as evidenced by the large changes in counts at the bottom but much smaller changes above the bottom of the NAT. The perching of water above the clay layer enables most or all of the infiltration to be measured during NAT monitoring at this date.

4.2 Soil Gas Monitoring

Samples were collected from soil gas sampling ports at the CFA landfills semiannually from December 1996 to July 1998. Results of the analysis of the gas samples are listed in Table 4-3. Appendix C contains a complete list of the gas sample results.

Seven of the 18 VOCs evaluated in the gas sampling show consistent positive detections. 1,1,1-Trichloroethane, 1,1-dichloroethane, 1,1-dichlorethene, and trichloroethene are commonly found in solvents used for cleaning mechanical equipment. Dichlorodifluoromethane and trichlorofluoromethane are freons used in cooling systems. Methane is a common by-product of the anaerobic degradation of landfill wastes.

Other than methane, 1,1,1-trichloroethane was the compound detected at the highest concentrations with a maximum detection of 14,000 ppbv in GSP 3-1 in February 1998. The contaminants 1,1-dichloroethene and 1,1-dichloroethane were usually associated with 1,1,1-trichloroethane, but both compounds occurred at lower concentrations than 1,1,1-trichloroethane. The contaminants 1,1-dichloroethene and 1,1-dichloroethane are probably biodegradation products of 1,1,1-trichloroethane.

The highest gas-phase VOC concentrations in the individual boreholes were detected with equal frequency at the two intermediate sampling ports approximately 12.2 m (40 ft) and 21.3 m (70 ft) below grade. The soil gas ports were installed adjacent to known fracture zones in the basalt. The organic vapors are probably migrating through preferential vertical and horizontal flow paths in the fractured basalt. The mechanism of vadose zone transport for these compounds could be leaching or density driven advective transport of the gas. In order to assess the potential impact of the vapor concentrations measured in the CFA landfill vadoze zone wells, vapor and groundwater data from the Radioactive Waste Management Complex (RWMC) were reviewed. TCE concentrations from 21 m (70 ft) bgs in the

Table 4-3. Soil gas sample results (concentrations in ppbv).[a]

	GSP 1-1[b]				GSP 2-1[c]				GSP 2-2[d]				GSP 3-1[e]				GSP 3-2[f]			
Depth	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98
1,1,1-Trichloroethane																				
12.5	170	380	1,500	200	11	3	48	nd	700	460	2,100	420	4	540	1,200	390	72	61	1,100	12
37.5	570	620	3,700	570	nd	7	72	7.6	1,000	700	2,100	210	1,500	1,800	8,800	960	400	450	1,200	300
77.5	nd	2,700	11,000	1,000	27	29	280	12	370	270	640	120	2,300	3,600	14,000	2,900	630	530	3,100	230
107.5	190	370	4,500	550	nd	17	120	3.9	110	280	1,400	4.1	170	260	3,700	350	6	13	5	4.4
1,1-Dichloroethane																				
12.5	24	40	160	28	6	nd	4	nd	1,400	940	2,200	420	nd	34	160	20	15	12	78	8.6
37.5	75	72	280	87	nd	nd	4	4	2,000	1,500	2,600	590	210	280	640	220	160	100	240	85
77.5	nd	20	140	16	12	11	64	6	390	220	330	160	120	17	170	28	53	43	260	19
107.5	nd	nd	13	11	nd	9	34	39	48	160	620	4.1	nd	nd	20	11	nd	nd	nd	4.4
1,1-Dichloroethene																				
12.5	56	92	320	48	nd	nd	nd	nd	83	46	220	22	nd	170	260	62	nd	nd	27	8.6
37.5	180	190	690	150	nd	nd	nd	nd	110	68	250	23	360	600	2,500	390	4	nd	120	9.9
77.5	nd	1,100	3,700	880	nd	nd	nd	nd	38	14	16	6	1,300	2,100	4,700	870	76	46	260	13
107.5	78	220	1,600	280	nd	nd	nd	nd	11	14	120	4.1	75	100	1,400	140	2	4	nd	4.4
1,2-Dichloropropane																				
12.5	nd	nd	3	10	nd	nd	nd	nd	8	7	65	4.9	nd	nd	nd	7.4	nd	nd	nd	nd
37.5	nd	nd	13	12	nd	nd	nd	nd	9	7	54	10	nd	3	26	11	nd	nd	nd	nd
77.5	nd	nd	nd	12	nd	nd	nd	nd	nd	nd	3	10	nd	nd	nd	12	nd	nd	nd	nd
107.5	nd	nd	nd	11	nd	nd	nd	nd	nd	nd	3	4.1	nd	nd	nd	11	nd	nd	nd	nd
1,2-Dichloroethane																				
12.5	nd	nd	4	10	nd	nd	nd	nd	nd	nd	nd	30	nd	nd	6	7.4	nd	nd	nd	nd
37.5	7	6	32	4.7	nd	nd	8	4	nd	nd	nd	10	6	6	41	5.4	nd	nd	nd	nd
77.5	nd	8	48	12	nd	nd	nd	4	nd	nd	5	10	7	4	24	12	nd	nd	nd	nd
107.5	nd	nd	9	11	nd	nd	8	3.9	nd	nd	nd	4.1	nd	nd	6	11	nd	nd	nd	nd
Benzene																				
12.5	nd	nd	nd	10	nd	nd	nd	nd	nd	4	nd	11	nd	nd	nd	7.4	nd	11	nd	8.6
37.5	nd	nd	nd	22	nd	nd	nd	nd	nd	nd	8	10	nd	nd	nd	11	nd	nd	nd	9.9
77.5	nd	nd	nd	12	nd	nd	nd	nd	nd	nd	nd	10	nd	nd	nd	12	nd	nd	nd	10

Table 4-3. (continued).

	GSP 1-1[b]				GSP 2-1[c]				GSP 2-2[d]				GSP 3-1[e]				GSP 3-2[f]			
Depth	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98
107.5	1	nd	nd	11	nd	nd	nd	nd	nd	nd	nd	4.1	nd	nd	6	46	nd	nd	nd	4.4
Acetone																				
12.5	nd	nd	nd	nd	nd	nd	nd	nd	12	nd	nd	26	6	22	nd	17	19	22	30	45
37.5	nd	nd	nd	nd	nd	nd	nd	20	nd	nd	60	50	nd	nd	78	49	nd	nd	nd	27
77.5	nd	nd	nd	nd	9	16	nd	20	nd	nd	19	22	16	nd	38	58	25	nd	42	23
107.5	nd	nd	nd	nd	nd	nd	nd	20	10	nd	45	23	nd	nd	nd	260	12	nd	nd	25
Carbon Tetrachloride																				
12.5	nd	nd	13	10	3	nd	18	nd	nd	nd	11	11	nd	nd	21	74	nd	nd	12	8.6
37.5	nd	nd	13	12	nd	nd	29	4	nd	nd	24	10	nd	nd	31	11	nd	nd	3	9.9
77.5	nd	nd	39	12	9	9	110	4.4	4	4	13	10	nd	nd	79	12	nd	nd	14	10
107.5	nd	nd	15	11	nd	5	40	3.9	2	6	77	4.1	nd	nd	27	11	nd	nd	6	4.4
Chloroethane																				
12.5	nd	nd	3	10	nd	nd	nd	nd	14	13	64	6.1	nd	nd	nd	7.4	nd	nd	nd	nd
37.5	nd	nd	5	12	nd	nd	nd	nd	15	18	70	29	nd	nd	14	11	nd	nd	nd	nd
77.5	nd	nd	5	12	nd	nd	nd	nd	4	210	nd	5.6	2	nd	9	9.9	nd	nd	nd	nd
107.5	nd	nd	nd	11	nd	nd	nd	nd	nd	nd	20	4.1	nd	nd	nd	11	nd	nd	nd	nd
Chloroform																				
12.5	nd	nd	8	10	nd	nd	11	nd	8	5	30	5.5	nd	nd	nd	7.4	nd	nd	4	8.6
37.5	2	nd	17	12	nd	nd	nr	4	9	7	36	4.3	7	6	38	8	3	nd	13	9.9
77.5	nd	3	19	12	2	nd	13	4	3	nd	4	10	6	nd	30	5.2	nd	nd	6	10
107.5	nd	nd	5	11	nd	nd	6	3.9	nd	nd	14	4.1	nd	nd	7	11	nd	nd		4.4
Chloromethane																				
12.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	11	nd	nd	nd	nd	nd	nd	nd	nd
37.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	10	nd	nd	nd	nd	nd	nd	nd	nd
77.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	23	nd	10	nd	nd	nd	nd	nd	nd	nd	nd
107.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	4.1	nd	nd	nd	nd	nd	nd	nd	nd
Dichlorodifluoromethane																				
12.5	36	60	380	40	86	35	680	nd	260	300	630	100	nd	140	340	71	40	19	530	3.8
37.5	120	130	680	140	2	110	280	68	310	440	870	130	300	700	1,300	320	370	260	860	150

Table 4-3. (continued).

	GSP 1-1[b]				GSP 2-1[c]				GSP 2-2[d]				GSP 3-1[e]				GSP 3-2[f]			
Depth	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98
77.5	nd	120	580	69	180	260	1,700	120	300	310	430	160	30	350	370	210	440	410	2,200	140
107.5	7	18	220	38	nd	150	150	9.6	190	320	1,200	4.1	7	13	300	27	260	34	nd	4.4
Methane																				
12.5	369	nd	4,400	1,700	2,212	1,600	2,300	nd	698	2,300	6,500	1,800	414	3,600	4,100	2,200	439	nd	3,600	1,600
37.5	619	4,300	9,600	2,500	508	Nd	2,800	1,900	1,249	2,300	20,400	2,600	959	nd	19,700	3,400	594	nd	23,400	2,000
77.5	418	nd	8,500	2,100	1,361	3,940	14,900	2,000	1,502	320	7,700	2,500	1,186	nd	18,200	4,600	1,319	nd	35,500	2,800
107.5	439	3,600	5,800	2,100	401	nd	3,100	1,800	899	5,560	14,400	1,800	413	5,300	8,300	1,900	427	3,880	3,600	1,700
Methylene Chloride																				
12.5	nd	nd	nd	nr	nd	nd	nd	nd	3	nd	10	nr	nd	3	10	nr	nd	nd	nd	nr
37.5	nd	nd	4	nr	nd	nd	nd	nd	29	32	130	nr	12	8	66	nr	nd	nd	22	nr
77.5	nd	nd	6	nr	nd	nd	nd	nd	2	nd	nd	nr	66	21	100	nr	61	14	14	nr
107.5	nd	nd	nd	nr	nd	nd	nd	nd	nd	nd	10	nr	nd	nd	10	nr	nd	nd	nd	nr
Tetrachloroethene																				
12.5	13	30	88	17	13	7	39	nd	62	42	300	nd	nd	3	22	3.1	8	14	65	8.6
37.5	21	31	220	42	2	19	110	9	99	130	98	64	84	130	250	110	58	76	120	49
77.5	nd	6	34	12	32	34	250	17	57	130	98	34	14	nd	22	12	2	nd	10	10
107.5	nd	nd	4	11	nd	20	81	3.9	21	75	210	4.1	nd	nd	15	11	nd	nd	nd	4.4
Trans-1,1-Dichloroethene																				
12.5	nd	nd	nd	nd	nd	nd	nd	nd	2	nd	8	11	nd	nd	nd	7.4	nd	nd	nd	nd
37.5	nd	nd	nd	nd	nd	nd	nd	nd	2	nd	nd	10	nd	nd	3	11	nd	nd	nd	nd
77.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	10	nd	nd	nd	12	nd	nd	nd	nd
107.5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	4.1	nd	nd	nd	11	nd	nd	nd	nd
Trichloroethene																				
12.5	21	46	150	32	10	4	53	nd	50	26	350	15	nd	7	100	5.1	18	27	140	3.9
37.5	49	51	260	62	nd	5	55	4	67	65	290	34	120	nd	460	130	79	92	170	57
77.5	nd	350	1,400	170	11	5	68	4	34	8	60	17	50	nd	200	18	15	14	110	10
107.5	27	39	510	77	nd	5	33	3.9	9	8	160	4.1	nd	7	88	11	nd	nd	6	4.4
Trichlorofluoromethane																				
12.5	46	90	530	71	60	22	90	nd	79	95	360	64	nd	nd	nd	nd	57	32	900	5.8

Table 4-3. (continued).

	GSP 1-1[b]				GSP 2-1[c]				GSP 2-2[d]				GSP 3-1[e]				GSP 3-2[f]			
Depth	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98	12/18/96	7/15/97	2/24/98	7/6/98
37.5	190	200	970	230	nd	46	160	20	150	210	660	100	nd	nd	nd	nd	470	430	1,400	280
77.5	nd	340	1,100	150	66	69	340	38	340	320	560	250	nd	nd	nd	nd	580	580	3,000	230
107.5	11	31	360	67	nd	34	130	3.9	180	320	1,400	4.1	nd	nd	nd	nd	12	29	nd	4.4

a. Only compounds that were detected are shown in this table. For a complete list of analytes see Appendix C.

b. Depths shown are proposed depths in the work plan. Actual sample depths are 8.5–11.5 ft, 43–46 ft, 64–67 ft, and 95–98 ft.

c. Depths shown are proposed depths in the work plan. Actual sample depths are 11–14 ft, 41–46 ft, 66–69 ft, and 94–97 ft.

d. Depths shown are proposed depths in the work plan. Actual sample depths are 15–18 ft, 39–42, 64–67, and 90–99 ft.

e. Depths shown are proposed depths in the work plan. Actual sample depths are 11–14 ft, 40–43 ft, 74–77 ft and 101–104 ft.

f. Depths shown are proposed depths in the work plan. Actual sample depths are 9–12 ft, 44–47 ft, 68–71 ft, and 101–104 ft.

nd = not detected.

nr = not reported.

vadose zone at RWMC are two to three orders of magnitude higher than the concentrations measured at the same depth near the landfills. The resultant concentration in groundwater at the RWMC is undetected to 2 ug/L. Therefore, it is very unlikely that the observed concentrations at the CFA landfills will impact the SRPA above MCLs (see Appendix E for more detail).

Given the age of the landfills, it is possible that vadoze zone gas concentrations were higher in the past and that the majority of contaminants may have migrated away from the landfill. However, this does not mean that soil gas concentrations are greater at depths below the deepest GSP sampling port because contaminant concentrations in soil gas tend to decrease due to dilution, vertical and horizontal diffusion, and dispersion of vapors as they migrate over larger areas. One line of evidence against higher concentrations having migrated to depth is that the concentrations uniformly attenuate with depth.

4.3 Groundwater Monitoring

This section describes the analysis and interpretation of water-level measurements and groundwater sampling results. Eight quarters of groundwater-level measurements were collected monthly from 27 aquifer wells at or near the CFA between May 1996 and October 1998 using an electric water-level indicator to measure water levels. Eleven wells were sampled quarterly for two years from July 1996 to April 1998.

4.3.1 Water Level Data

The depth to groundwater measurements were converted to water-table elevations using surveyed measuring-point elevations and well deviation correction factors. Table 4-4 provides a summary of the data set. Water-level measurements are not available for the entire eight quarters for CFA-MON-A-001, CFA-MON-A-002, and CFA-MON-A-003. Out of a total of 692 water level measurements, 35 appeared anomalous and were removed. These anomalous points yielded outlying water-table elevations that ranged from a minimum of 1,353 m (4,442 ft) above mean sea level to a maximum of 1,360 m (4,464 ft) above mean sea level; with these removed, the calculated water table elevations of the remaining data set range from 1,360 to 1,358 m (4,446 to 4,458 ft) above mean sea level.

The anomalies are most likely the result of inaccurate field measurement of the water depth (i.e., human error or malfunctioning electric water level probe). The appearance of gaps in the hydrograph represents either a point where no data were collected or, more likely, where data were determined to be anomalous and, therefore, removed from the record.

4.3.1.1 Hydrograph Analysis. For discussion purposes, the set of 27 wells is divided into six groups of three to six wells by area. The six groups are: (1) the wells immediately south and east of INTEC (Figure C-16), (2) the six Theis wells (Figure C-17), (3) the wells that comprise the remainder of the arc installed as part of the INTEC plume tracer studies (Figure C-18), (4) Landfill II wells including USGS 20 (Figure C-19), (5) the Landfill III wells and USGS 085 (Figure C-20), and (6) the three CFA monitoring wells (Figure C-21).

For each group, the following four different graphics are provided:

- A plan view showing the position of the wells relative to the CFA
- A hydrograph featuring time-series water level elevations for each well in that group

Table 4-4. Summary of water level data for 8-quarter period (May 1996 to October 1998).

Number of Wells	Number of Measurements per Well	Total Number of Water Level Measurements	Total Number of Removed Data	Minimum Calculated Water Table Elevation (ft-amsl)	Maximum Calculated Water Table Elevation (ft-amsl)
27	26 (average) 8–29 (range)	692	35	4,446	4,458

- A diagram of basic well construction details (land surface, completion depth, and open intervals) and showing June 1998 water levels for the group

- A diagram showing generalized lithology sequences for the saturated portion of each well in the group.

Three different generalized lithology types are given in these last diagrams: basalt, sediment, and rubbly basalt interflow zones. Hydraulic conductivity of the basalt in the upper 244 m (800 ft) of the aquifer generally is 0.3 to 30.5 m/day (1 to 100 ft/day). Sedimentary interbeds are generally orders of magnitude less permeable. Saturated hydraulic conductivity of interbeds at various locations at the INEEL ranges from 1.5E-5 to 2.9 m/day (4.9E-5 to 9.6 ft/day). Rubbly interflow zones are believed to be extremely transmissive and may act as conduits that control flow in the saturated zone.

The records used to prepare the lithologic diagrams (that were extracted from the Comprehensive Well Survey [DOE-ID 1994]) are based on drill and geophysical well logs. The diagrams show only the saturated portion and any unsaturated lithology from the bottom of the well up to an altitude of 1,371 m (4,500 ft) above mean sea level. The elevations of well details are based on the NGVD 29 datum. Most of the brass cap and measuring points of these wells have been resurveyed within the last 3 to 6 years by INEEL (or predecessor contractor) personnel.

4.3.1.1.1 Group 1—The first group (Figure C-16) includes USGS 82, which has an estimated water level error of 0.09 m (0.3 ft). The hydrograph in Figure C-16 suggests that this is the upgradient well of this group, which is expected from its northerly position relative to the other wells. Wells USGS 82 and USGS 57 are older cable-tool drilled wells that can be regarded as relatively true and plumb. The water level of Well USGS 57 is consistently lower than that of USGS 82; the average uncorrected water level difference between the two is 0.24 m (0.8 ft) for the 8-quarter period. Well USGS 57 is about 1.6 km (1.0 mi) west-southwest from Well USGS 82 (505 m [1,660 ft] south, 1,702 m [5,585 ft] west). Well USGS 111 is also nearly 1.6 km (1.0 mi) southwest from Well USGS 82 (906 m [2,975 ft] south, 1,239 m [4,065 ft] west). The hydrographs of USGS 57 and USGS 111 relative to USGS 82 are consistent with the conceptual model that assumes a local groundwater flow direction to the southwest. Oddly, the water levels measured in USGS 116 appear to be roughly the same altitude as those measured in USGS 82.

Well USGS 116 is about 0.96 m (0.6 mi) southwest from USGS 82 (902 m [2,960 ft] south, 509 m [1,670 ft] west). If the direction of maximum groundwater hydraulic gradient is southwest with a value of about 0.8 m/km (4 ft/mile), then there should be about a 0.15 m (0.5-ft) difference between these two hydrographs. According to Table 3-3, the first-order formula adds about 0.03 m (0.1 ft) to the uncorrected USGS 116 water level. For the eight-quarter period, the water level calculated for USGS 116 averages about 0.05 m (0.18 ft) greater than USGS 82. The estimated water-level error-band for USGS 116 is only about 0.7 m (0.25 ft). Figure C-16 shows that USGS 82 penetrates about 30 m

(100 ft) further into the aquifer than USGS 116. Well USGS 82 also intercepts two interbeds and two rubbly zones in the saturated zone, none of which are present at USGS 116. The interbeds might confine a portion of the aquifer, which would probably push up the water level in a well that penetrates the unit. As such, the lithology difference between the two wells does not explain why the USGS 116 water levels are at the same elevation as USGS 82. The water level difference may be related to the deviation correction for USGS 116.

4.3.1.1.2 Group 2—The second group (Figure C-17) consists of the six Theis wells. These wells are about 152 m (500 ft) apart and form a 0.80 km (0.5-mi) long arc southwest of INTEC. These wells were installed to intercept a saline plume originating from INTEC in the late 1950s (Wood et al. 1989). The plume was not intercepted in these wells, although it was detected later in wells installed almost directly south of INTEC. This indicates the local gradient may at times be mostly southward. Figure C-17 contains both the uncorrected and corrected forms of the USGS 35 hydrograph. The corrected form is significantly higher, while the uncorrected form is slightly lower than surrounding wells. Well USGS 35 is completed in a rubbly basalt zone. However, rubbly zones appear in USGS 39 at the water table and the water-table elevation determined that this well is consistent with surrounding wells. Well USGS 35 probably should not be corrected with the first-order correction since the well was dug by the more true and plumb cable-tool method. The 0.09 m (0.3-ft) error band added to the hydrograph allows it to overlap the hydrographs of surrounding wells. Well USGS 38, which has the shortest open interval (15 m [51 ft]) in this group, is about 45 m (150 ft) deeper than the other five and is completed amidst several interbeds. Surprisingly, the USGS 38 well hydrograph remains at about the same elevation as the hydrographs for USGS 35, 36, 37, and 39.

4.3.1.1.3 Group 3—The third group (Figure C-18) consists of five wells that are south of INTEC. Most of these wells were installed to intercept the saline plume that was not detected in the wells of the Theis arc. The wells in this group were completed at about the same depth and are open over similar intervals as the six Theis wells in Group 2. Well USGS 112, 113, and 114 intercept rubble zones. Well USGS 77, 114, and 115 intercept some interbed material. Well USGS 77, the deepest of the group, is completed just beneath a relatively thick interbed. The hydrograph for Well USGS 113 appears anomalous relative to the other wells. This is the first-order corrected water level. It is consistently about 0.3 m (1 ft) higher than the other wells in this group. The first-order correction adds about 1.8 m (6 ft) to the uncorrected water level. The lithology and construction details do not offer much insight. Well USGS 113 is about 278 m (915 ft) directly east of USGS 112 and about 330 m (1,085 ft) west of USGS 77. Well USGS 77 is about 18 m (60 ft) north of an imaginary east-west line that bisects Wells USGS 112 and USGS 113.

Despite their close proximity, the corrected hydrograph of USGS 113 remains an average of 0.18 m (0.6 ft) above the corrected hydrograph for USGS 112; this is within the 0.21-m (0.7-ft) error band estimated for USGS 113. However, the corrected hydrograph for USGS 113 averages about 0.4 m (1.5 ft) greater than USGS 77. Well USGS 113 intercepts some rubbly basalt that may act as a highly permeable interflow zone; these might be hydraulically connected with some upgradient source as previous studies have suggested (Wood et al. 1989). A similar water level might be expected in USGS 114, which crosses several possible interflow zones. However, the USGS 114 hydrograph remains at elevations similar to USGS 77, 112, and 115. Until this anomaly is explained, water-level data collected from USGS 113 should be considered questionable.

4.3.1.1.4 Group 4—The fourth group (Figure C-19) consists of the wells at Landfill II and Well USGS 20. Wells LF 2-08, LF 2-09, and LF 2-10 are within 60 m (200 ft) of each another. Wells LF 2-09, LF 2-10, and Well USGS 20 were drilled relatively deeper than LF 2-08 or LF 2-11 and intercept a common interbed at about 1,310 m (4,300 ft) amsl (see Figure C-19). Though LF 2-09 is deep, its open interval is relatively shallow and near the water-table surface (as with LF 2-08 and LF 2-11). Unfortunately, the hydrograph for well LF 2-11 does not sit above the other two as might be expected from its "upgradient" location. If error bands are added, the hydrographs for all three wells overlap. Wells LF 2-10 and USGS 20 are the deepest wells of the group and their hydrographs may indicate a downward gradient in the aquifer or that they intersect a hydraulically different part of the aquifer. Another explanation might be that the water level access for Well LF 2-10, which is the same as the pump discharge pipe and contains a check valve, may interfere with collection of the true water-level depth. The low water levels of USGS 20 may be the result of the interflow zones intercepted just beneath the water table at this well. Alternatively, this well, which is about 1.6 km (1 mi) east of LF 2-11, may be on the other side of a groundwater divide, rift zone, or other hydraulically altering subsurface feature.

4.3.1.1.5 Group 5—The fifth group (Figure C-20) consists of the wells created for monitoring Landfill III. These include Wells LF 3-08, LF 3-09, and LF 3-10. Well USGS 85 is also included in this group because it is believed to be upgradient of the landfill. The well-specific error associated with calculated water-table elevation for Wells LF 3-08, LF 3-09, LF 3-10 and USGS 85 are 0.15 m, 0.15 m, 0.09 m, and 0.03 m (0.5 ft, 0.5 ft, 0.3 ft, and 0.1 ft), respectively. The error estimates are helpful in explaining the hydrographs in Figure C-20. It is expected that the hydrograph for USGS 85 would be above the landfill wells. Well USGS 85 averages about 0.09 m (0.3 ft) above LF 3-10 and 0.06 m (0.2 ft) above LF 3-09 for the eight-quarter period. This supports the concept of a southward flowing groundwater gradient. However, Well USGS 85 averages about 0.24 m (0.8 ft) less than LF 3-08. The first-order correction for LF 3-08 adds about 1.4 m (4.7 ft) (see Table 3-3) to the uncorrected water level. LF 3-08 has a 3 m (10 ft) open interval, the narrowest of the four wells in this group (see Table 3-2). It is completed in fairly competent basalt without major rubble zones or interbeds. Although it is not shown in Figure C-20, the driller's log for Well LF 3-08 indicates a 0.9- to 1.8-m (3- to 6-ft) (or more) thick fracture system about 3 m (10 ft) below the open interval. This fracture may provide some hydraulic connection to water that is recharged from a source uncommon to the other wells in this group, creating some vertical hydraulic gradient present only at Well LF 3-08. Otherwise, this may be the artifact of a first-order water level correction. However, if error bands are added to the LF 3-08 and USGS 85 hydrographs, they will overlap.

4.3.1.1.6 Group 6—The sixth group of wells (Figure C-21) consists of the facility monitoring wells CFA-MON-A-001, CFA-MON-A-002, and CFA-MON-A-003. Monitoring Well CFA-MON-A-001 is about 22 m (75 ft) south and 518 m (1,700 ft) west of CFA-MON-A-002, which is about 3 m (10 ft) north and 457 m (1,500 ft) west of CFA-MON-A-003. The three wells form a nearly perfect east-west line south of the CFA. The saturated lithology beneath these wells consists mostly of competent basalt. Well CFA-MON-A-003 intersects interbed material near the water table. Water levels were not measured regularly at these three wells during the eight-quarter period and only about three quarters of data are available. The wells were drilled in late 1994 using the air-rotary tri-cone bit method. Deviation survey results have not been used to produce correction factors for these three wells. The lack of deviation correction factors for these three wells is the likely cause for the relative position of the hydrographs in Figure C-21. The wells are less than a third of a mile apart and are separated by only about 30 m (100 ft) relative to a southward gradient. The average water-level difference between CFA-MON-A-001 and CFA-MON-A-002 is 0.24 m (0.8 ft) and between CFA-MON-A-002 and CFA-MON-A-003 is 0.48 m (1.6 ft). This gradient fits within the regional average of 0.8 m/km (4 ft/mi); however, the direction of the gradient determined at these three wells indicates an easterly component to the groundwater flow.

4.3.1.2 *Temporal Trends.* Long-term and regional trends are evident from examining the set of 27 well hydrographs. Between May and December 1996, the hydrographs for most wells in the CFA set show a drop of about 0.15 m (0.5 ft). This is followed from December 1996 to April 1998 by a trend of increasing water levels that probably correspond with the ending of a regional 7-year drought. The average water-level increase over the 16-month period (December 1996 to April 1998) for 24 wells is 0.88 m (2.9 ft). This trend is evident in all wells in the CFA set.

A small amount of seasonal rise and fall during these 16 months is evident in some wells. From around May 1997 to September 1997, there appears to be a flattening of the general 16-month increasing trend (see USGS 35 hydrograph in Figure C-18b); this may be a regional-scale response to the 1997 growing season's groundwater irrigation demands. Following April 1998, there appears to be a slight decrease in water levels in all the wells. This may signal the use of groundwater during the 1998 growing season. The long-term water-level trends and relative water-table elevation of wells that are on the perimeter of the landfill study area show the temporal trends discussed above (Figure C-22).

4.3.1.3 *Groundwater Level Analysis.* Water-table contour plots can be misleading if the error associated with the data is not considered. Water-table elevation contouring errors fall into two general categories: (1) failure to exclude data points that are not representative and (2) failure to take into account subsurface features that change the distribution of potentiometric head as a result of aquifer heterogeneity or boundary conditions (Boulding 1995). The single most important consideration in preparing a potentiometric map is that the water-level measurements should describe a single flow system in an aquifer.

A water-level map is presented in Figure C-23 for June of 1998. Examination of Figure C-23 shows several wells (USGS 116, USGS 113, USGS 20, and the CFA-MON wells) with anomalous water levels.

A contour plot using water-table elevations measured in only nine of the 27 wells yields a more plausible representation of the true water-table elevation (Figure C-24). The nine wells were chosen based on their drilling method (wells dug using a cable-tool were given preference), estimated error (wells with lowest estimated error were selected), and location (perimeter wells were given preference). Although this contour plot may not provide local flow details, the result is a much less contorted contour plot and the plot appears to be more typical of the regional water table. The six groupings of wells depicted in Figures C-16 to C-21 are represented by a few data points each in this contour plot. Some wells, such as USGS 20, were deliberately left out if their water levels appeared consistent but anomalous.

4.3.1.4 *Groundwater Flow Analysis.* The direction of groundwater flow can be determined based on a line drawn perpendicular to the equipotential contour lines. Figure C-24 also provides some information regarding the magnitude of the maximum groundwater gradient in the CFA vicinity. Based on the contour positions, the gradient in the CFA area appears to vary from about 0.02 to 2.3 m/km (1 to 8 ft/mi). Between INTEC and the CFA the gradient appears small: between 0.133 and 0.170 m/km (0.7 and 0.9 ft/mi). South of the CFA, the gradient appears to increase to about 2.3 m/km (8 ft/mi). However, because the measured water levels in the three wells south of the CFA are suspiciously different, only one of three wells south of the CFA was used to prepare the contours. The apparently high gradient south of the CFA results from this lack of control in both well density and water-level accuracy. Between the CFA and INTEC, eight data points were used to prepare the contours. These vary from 1,358.3 to 1,358.7 m (4,456.6 to 4,457.7 ft), a difference of only 0.3 m (1.1 ft) over about 4 km (2.6 mi) in the direction of flow (roughly 0.08 m/km [0.4 ft/mi] gradient). This order of magnitude variation (0.08 m/km to 2.3 m/km [0.4 ft/mi to 8 ft/mi] is an increase by about 20 times) in hydraulic gradient over fairly short distances is either the result of: (1) subsurface features such as fracture or rift zones or (2) comparing areas of high well density to areas with few wells.

4.3.2 Groundwater Analytical Results

Eight quarters of groundwater samples have been collected from the CFA landfill wells and CFA facility monitoring wells. Landfill II utilized well LF 2-11 as an upgradient monitoring well and LF 2-08, LF 2-09, and LF 2-10 as downgradient monitoring wells. Landfills I and III are adjacent to each other and utilized the same monitoring wells. Landfills I and III utilized well USGS 85 as the upgradient monitoring well and wells LF 3-08, LF 3-09, and LF 3-10 as downgradient monitoring wells. The CFA facility monitoring wells CFA-MON-A-001, -002, and –003, were drilled in 1996 to monitor the new CFA sewage treatment facility. All the wells except USGS 85 and LF2-10 are completed at or just below the water table. USGS 85 and LF2-10 are screened 50 feet and 260 feet, respectively, below the water table. Figure 3-4 shows the well locations and Figures C-19 through C-21 show the subsurface relationships.

The groundwater was analyzed for the Contract Laboratory Program (CLP) target analyte list for VOCs plus 1-2 dichlorobenzene, napthalene, 1-2-4 trimethylbenzene, 1-3-5 trimethylbenzene, and 1-2-4 trichlorobenzene. The groundwater was analyzed for CLP metals plus alkalinity, fluoride, chloride, sulfate, and nitrate/nitrite. These analytes were selected to ensure a broad scope of contaminants was monitored and to provide enough data to perform water chemistry analysis on the groundwater.

Dissolved oxygen, pH, specific conductance, and temperature were collected at the well head as aquifer stabilization parameters. The inorganic constituents cadmium and zinc are identified in the monitoring work plan as groundwater COCs for Landfills I and III; beryllium, cadmium, and zinc are the groundwater COCs for Landfill II. A summary of the analytes detected, background values (if available), and regulatory levels is provided in Table 4-5. Tables 4-6 through 4-8 list the analytes detected, the maximum detected concentration, the average detected concentration, and the number of times the analyte was detected. The complete list of groundwater analytical results are in Appendix D and described below.

4.3.2.1 Major Ion Results. As Tables 4-6 through 4-8 show, the highest average chloride, sodium, potassium and magnesium concentrations occur in the shallow Landfill II wells (LF2-11, LF2-08 and LF2-09). The next highest concentrations occur in the shallow Landfill I/III wells (LF3-08, LF3-09 and LF3-10), followed by two of the facility monitoring wells (CFA-MON-002 and CFA-MON-003).

Graphical representations of the major ion compositions show that the wells can be sorted into three groups. Figure C-25 uses chloride concentration and the magnesium-to-calcium ratio to show the three groups. The first group consists of the monitoring wells completed at the water table (shallow monitoring wells) at the CFA Landfills II and I/III. This group is high in chloride relative to the other two groups. The second group consists of LF 2-10 and USGS 85, the deep landfill monitoring wells. The third group consists of the three CFA facility monitoring wells. The CFA facility monitoring wells show three differences in major ion chemistry from the landfill monitoring wells: (1) a much higher ratio of magnesium to calcium, (2) lower sodium and chloride concentrations, and (3) elevated nitrate concentrations in two of the three wells. The groundwater in two of the CFA facility monitoring wells is elevated in both nitrate and chloride.

Table 4-5. Background and regulatory levels for detected analytes.

Compound	Units	MDV	MCL or SMCL[a]	LF2-11 Upgradient Well ADV	Background[b]	Detections Above Background	Number of Wells with Detections Above MCL or SMCL	Number of Wells with More Than one Detection Above MCL or SMCL
Anions								
Alkalinity-Bicarbonate	mg/L	360	None	128	*208*	No	NA	NA
Chloride	μg/L	276	*250*	136	*19*	Yes	1	0
Fluoride	mg/L	0.24	*2*	0.2	0.5	No	0	0
Nitrate/Nitrite	mg-N/L	20.5	10	3.4	1 to 2	Yes	2	2
Sulfate	mg/L	38.3	*250*	33.4	*38,500*	No	0	0
Common Cations								
Calcium	μg/L	72,200	None	60,800	*52,000*	Yes	NA	NA
Magnesium	μg/L	24,500	None	16,695	*16,000*	Yes	NA	NA
Potassium	μg/L	6,880	None	4,257	*3,400*	Yes	NA	NA
Sodium	μg/L	54,600	None	46,729	*17,000*	Yes	NA	NA
Organic Analytes								
1,1,1-Trichloroethane	μg/L	0.4	200	0.3	NA	NA	0	0
1,2-Dichloroethane	μg/L	0.1	5	ND	NA	NA	0	0
1,2,4-Trimethylbenzene	μg/L	7	None	ND	NA	NA	NA	NA
1,3,5-Trimethylbenzene	μg/L	4	None	ND	NA	NA	NA	NA
Carbon Tetrachloride	μg/L	0.3	2	ND	NA	NA	0	0
Chloroform	μg/L	0.3	100	ND	NA	NA	0	0
Ethylbenzene	μg/L	0.1	700	ND	NA	NA	0	0
Naphthalene	μg/L	0.3	None	ND	NA	NA	NA	NA
Toluene	μg/L	22	1000	1.1	NA	NA	0	0
Trichloroethene	μg/L	0.2	5	ND	NA	NA	0	0

Table 4-5. (continued).

Compound	Units	MDV	MCL or SMCL[a]	LF2-11 Upgradient Well ADV	Background[b]	Detections Above Background	Number of Wells with Detections Above MCL or SMCL	Number of Wells with More Than one Detection Above MCL or SMCL
Xylene (total)	µg/L	0.7	10,000	ND	NA	NA	0	0
Inorganic Analytes								
Aluminum	µg/L	187	*50 to 200*	37.9	N	N	0	0
Arsenic	µg/L	2.2	50	1	2 to 3	No	0	0
Barium	µg/L	199	2,000	167	50 to 70	Yes	0	0
Cadmium	µg/L	7	5	0.2	<1	Yes	1	0
Chromium	µg/L	50.3	100	23.2	2 to 3	Yes	0	0
Copper	µg/L	36.1	1,000	31.3	*<1*	Yes	0	0
Iron	µg/L	54,600	*300*	2,179	*2*	Yes	6	5
Lead	µg/L	44.8	15*	4	1 to 5	Yes	3	1
Manganese	µg/L	170	*50*	18.6	*7*	Yes	1	0
Mercury	µg/L	3.7	2	ND	N	N	1	0
Nickel	µg/L	116	None	24.9	N	N	NA	NA
Selenium	µg/L	10.8	50	2.6	<1	Yes	0	0
Vanadium	µg/L	5.1	None	2.6	N	N	NA	NA
Zinc	µg/L	770	*5,000*	44	*14.5*	Yes	0	0

*The tap water action level for lead is 15 ug/L.

a. Numbers in italics are secondary maximum contaminant levels (SMCLs).

b. Background data are from two sources. Plain numbers are from Knobel et. al. 1992. Italic numbers are from Crockett, 1995.

NA = not applicable.

ND = not detected.

N = not determined.

Table 4-6. Detected Analytes from CFA Landfill II Monitoring Wells.

			LF2-11			LF2-08			LF2-09			LF2-10		
		MCL or	Upgradient Well			Downgradient Wells								
	Units	SMCL[a]	MDV	ADV	NTD	MDV	ADV	NTD	MDV	ADV	NTD	MDV	ADV	NTD
Anions														
Bicarbonate	mg/L	None	152	128	7/7	160	122	7/7	134	113	7/7	180	161	7/7
Chloride	mg/L	*250*	145	136	8/8	276	160	8/8	133	123	8/8	35	30	8/8
Fluoride	mg/L	*2*	0.21	0.2	8/8	0.2	0.2	8/8	0.2	0.2	8/8	0.19	0.2	8/8
Nitrate/nitrite	mg-N/L	*10*	3.4	3.4	2/2	3.7	3.7	2/2	3.4	3.4	2/2	1.3	1.3	2/2
Sulfate	mg/L	*250*	38.3	33.4	8/8	36.9	33.7	8/8	37.5	32.7	8/8	37.4	32.8	8/8
Common Cations														
Calcium	µg/L	None	72,000	60,831	8/8	72,200	68,338	8/8	71,100	64,113	8/8	63,700	53,506	8/8
Magnesium	µg/L	None	19,900	16,695	8/8	19,000	18,350	8/8	17,900	17,000	8/8	18,000	15,135	8/8
Potassium	µg/L	None	5,120	4,257	8/8	6,880	5,015	8/8	7,420	5,766	8/8	2,640	2,184	8/8
Sodium	µg/L	None	54,600	46,729	8/8	44,800	42,525	8/8	46,900	43,963	8/8	12,400	11,557	7/8
Organic Analytes														
1,1,1-Trichloroethane	µg/L	200	0.4	0.3	3/8	0.4	0.3	3/8	0.4	0.3	3/9	0.3	0.2	2/9
1,2,4-Trimethylbenzene	µg/L	None	ND	ND	0/8	0.2	0.2	1/8	ND	ND	0/9	ND	ND	0/9
Chloroform	µg/L	100	ND	ND	0/8	0.5	0.5	2/8	0.3	0.3	2/9	ND	ND	0/9
Naphthalene	µg/L	None	ND	ND	0/8	0.3	0.3	1/8	0.1	0.1	1/9	ND	ND	0/9
Toluene	µg/L	1,000	2	1.1	2/8	0.7	0.5	2/8	22	5.2	8/9	ND	ND	0/9
Trichloroethene	µg/L	5	ND	ND	0/8	0.1	0.1	2/8	ND	ND	0/9	ND	ND	0/9

Table 4-6. (continued).

		MCL or SMCL[a]	LF2-11			LF2-08			LF2-09			LF2-10		
			Upgradient Well			Downgradient Wells								
	Units		MDV	ADV	NTD	MDV	ADV	NTD	MDV	ADV	NTD	MDV	ADV	NTD
Inorganic Analytes														
Aluminum	µg/L	*50 to 200*	61.2	37.9	3/8	83.9	58.5	2/8	186	87.3	3/8	18	18	1/8
Antimony	µg/L	50	ND	ND	0/8	0.4	0.4	1/8	ND	ND	0/8	ND	ND	0/8
Arsenic	µg/L		1.3	1	7/7	1.3	1.1	7/7	2.2	1	7/7	1.7	1.4	7/7
Barium	µg/L	2,000	199	167.1	8/8	162	152.8	8/8	187	173.3	8/8	94.3	78.2	8/8
Cadmium	µg/L	5	0.36	0.2	3/6	1.5	0.6	5/6	**7**	1.9	4/6	0.24	0.2	1/6
Chromium	µg/L	100	23.2	11.7	4/8	13.2	10.7	3/8	50.3	20.4	5/8	14.2	10.1	6/8
Cobalt	µg/L	None	ND	ND	0/8	ND	ND	0/8	6.6	6.6	1/8	ND	ND	0/8
Copper	µg/L	1,000	31.3	31.3	1/8	45.3	28.5	2/8	36.1	19.3	2/8	1.1	1.1	1/8
Iron	µg/L	*300*	6,690	2,179	7/7	242	131	5/7	54600	8864	7/7	44.2	21.6	5/7
Lead	µg/L	15[b]	10.3	4	3/7	4.9	3	4/7	**30.2**	7.7	5/7	2	1.2	4/7
Manganese	µg/L	*50*	41.1	18.6	8/8	2.7	2.1	3/8	170	33.5	6/8	2.7	1.2	3/8
Mercury	µg/L	2	ND	ND	0/8	0.1	0.1	1/8	ND	ND	0/8	ND	ND	0/8
Nickel	µg/L	None	44.7	24.9	8/8	1.6	1.6	1/8	35.3	18.5	2/8	1.1	1.1	1/8
Selenium	µg/L	50	3.3	2.6	3/6	3.4	2.5	2/7	10.8	5.1	3/7	3	2.4	3/6
Vanadium	µg/L	None	2.6	2.6	1/8	4.5	4.1	2/8	5.1	4.1	2/8	4	4	1/8
Zinc	µg/L	*5,000*	101	44	8/8	65.1	31.5	8/8	770	162	7/8	21.8	11.2	8/8

a. The numbers in italics are secondary maximum contaminant levels (SMCLs).

b. The tap water action level for lead is 15 µg/L

ADV = Average Detected Value MDV = Maximum Detected Value ND = Not Detected NTD = Number of Times Detected

Concentration in Bold is above the MCL for that analyte.

Table 4-7. Detected analytes from Landfills I and III Monitoring Wells.

			USGS-85			LF3-08			LF3-09			LF3-10		
		MCL or	Upgradient Well			Downgradient Wells								
	Units	SMCL[a]	MDV	ADV	NTD	MDV	ADV	NTD	MDV	ADV	NTD	MDV	ADV	NTD
Anions														
Bicarbonate	mg/L	None	176	153.4	7/7	140	125.1	7/7	360	166.3	6/6	160	142	7/7
Chloride	mg/L	*250*	45.2	39.1	8/8	120	107.9	8/8	120	112.7	7/7	101	93.7	8/8
Fluoride	mg/L	*2*	0.21	0.2	8/8	0.21	0.2	8/8	0.22	0.2	7/7	0.21	0.2	8/8
Nitrate/nitrite	mg-N/L	*10*	2.31	2	8/8	3.3	3.3	2/2	3.9	3.9	2/2	4.07	3	8/8
Sulfate	mg/L	*250*	38.2	33.8	8/8	35.3	31.2	8/8	66.5	36.3	7/7	36.6	31.6	8/8
Common Cations														
Calcium	µg/L	None	60,700	51,948	8/8	64,400	55,580	8/8	70,100	66,029	7/7	67,100	55,701	8/8
Magnesium	µg/L	None	15,700	13,423	8/8	18,200	15,368	8/8	20,400	19,071	7/7	17,800	13,941	8/8
Potassium	µg/L	None	3,350	2,654	8/8	5,130	4,344	8/8	4,560	4,321	7/7	4,680	3,715	8/8
Sodium	µg/L	None	19,200	16,184	8/8	43,600	36,599	8/8	39,000	36,586	7/7	38,600	33,048	8/8
Organic Analytes														
1,1,1-Trichloroethane	µg/L	200	0.3	0.3	2/8	0.4	0.3	3/9	0.5	0.4	2/7	0.4	0.3	3/8
Toluene	µg/L	1,000	0.2	0.2	1/8	ND	ND	0/9	8	1.1	1/7	ND	ND	0/8
Trichloroethene	µg/L	5	ND	ND	0/8	0.1	0.1	1/9	ND	ND	0/7	ND	ND	0/8

Table 4-7. (continued).

	Units	MCL or SMCL[a]	USGS-85			LF3-08			LF3-09			LF3-10		
			Upgradient Well			Downgradient Wells								
			MDV	ADV	NTD	MDV	ADV	NTD	MDV	ADV	NTD	MDV	ADV	NTD
Inorganic Analytes														
Aluminum	µg/L	*50 to 200*	13.4	8.9	2/8	187	95.6	7/8	51.8	51.8	1/7	89.4	69.2	3/8
Arsenic	µg/L	50	1.9	1.4	7/7	1.5	1.2	7/7	1.1	1	6/6	1.2	1.1	6/7
Barium	µg/L	2,000	108	90	8/8	137	101.9	8/8	135	125.9	7/7	143	105.2	8/8
Cadmium	µg/L	5	0.28	0.3	1/6	0.32	0.2	3/6	0.24	0.2	4/6	0.37	0.1	4/6
Chromium	µg/L	100	18.3	13.7	8/8	14.6	9.8	6/8	43.6	30.6	7/7	26.8	18.7	8/8
Cobalt	µg/L	None	ND	ND	0/8	ND	ND	0/8	0.6	0.6	1/7	ND	ND	0/8
Copper	µg/L	1,000	1.1	1.1	1/8	0.94	0.9	1/8	13	7.4	2/7	1.1	1.1	1/8
Iron	µg/L	*300*	78.3	46.5	5/7	587	266.7	6/7	254	168.4	7/7	628	342.3	7/7
Lead	µg/L	15[b]	2.8	1.8	4/7	2.3	1.8	5/7	3.2	2.4	3/6	0.73	0.6	2/7
Manganese	µg/L	*50*	4.8	3	6/8	9.4	5.3	7/8	21.8	8.1	7/7	13.8	6	7/8
Mercury	µg/L	2	ND	ND	0/8	3.7	0.4	1/8	ND	ND	0/7	ND	ND	0/8
Nickel	µg/L	None	1.2	1.2	1/8	1.8	1.8	1/8	116	88.6	7/7	102	42.8	8/8
Selenium	µg/L	50	1.3	1.3	1/6	1.3	1.3	1/6	3.1	2.5	3/6	0.8	0.5	2/7
Vanadium	µg/L	None	3.5	2.1	2/8	0.55	0.5	2/8	3.2	3.2	1/7	0.68	0.4	2/8
Zinc	µg/L	*5,000*	13.1	6.5	4/8	129	82.6	7/8	201	103.5	7/7	298	198.6	7/8

a. The numbers in italics are for secondary maximum contaminant levels (SMCLs)

b. Tap water action level for lead is 15 µg/L

ADV = Average Detected Value MDV = Maximum Detected Value NTD = Number of Times Detected ND = Not Detected

Table 4-8. Detected analytes from the Sewage Treatment Facility Monitoring Wells.

	Units	MCL or SMCL[a]	CFA-MON-001 MDV	CFA-MON-001 ADV	CFA-MON-001 NTD	CFA-MON-002 MDV	CFA-MON-002 ADV	CFA-MON-002 NTD	CFA-MON-003 MDV	CFA-MON-003 ADV	CFA-MON-003 NTD
Anions											
Bicarbonate	mg/L	None	108	102	6/6	120	108.9	7/7	110	98.6	7/7
Chloride	mg/L	*250*	25.2	22.5	8/8	55.6	51.9	8/8	42.9	40.6	8/8
Fluoride	mg/L	2	0.24	0.2	8/8	0.2	0.2	8/8	0.23	0.2	8/8
Nitrate/nitrite	mg-N/L	10	2.25	1.9	8/8	**20.5**	**17**	8/8	**11**	9.4	8/8
Sulfate	mg/L	*250*	32.4	22.4	8/8	39	31	8/8	31.5	26.1	8/8
Common Cations											
Calcium	µg/L	None	33,900	28,491	8/8	61,500	52,048	8/8	45,900	39,234	8/8
Magnesium	µg/L	None	14,100	12,039	8/8	24,500	21,224	8/8	20,700	17,769	8/8
Potassium	µg/L	None	3,270	2,558	8/8	3,990	3,322	8/8	3,610	2,895	8/8
Sodium	µg/L	None	10,300	9,577	7/8	16,100	15,386	7/8	12,100	11,486	7/8
Organic Analytes											
1,1,1-Trichloroethane	µg/L	200	ND	ND	0/9	0.3	0.2	3/9	0.1	0.1	1/9
1,2,4-Trimethylbenzene	µg/L	None	ND	ND	0/9	7	5.1	9/9	ND	ND	0/9
1,2-Dichloroethane	µg/L	5	ND	ND	0/9	0.1	0.1	1/9	ND	ND	0/9
1,3,5-Trimethylbenzene	µg/L	None	ND	ND	0/9	4	3.1	9/9	ND	ND	0/9
Carbon tetrachloride	µg/L	5	ND	ND	0/9	0.3	0.2	3/9	ND	ND	0/9
Ethylbenzene	µg/L	700	ND	ND	0/9	0.1	0.1	1/9	ND	ND	0/9
Toluene	µg/L	1,000	ND	ND	0/9	0.3	0.3	2/9	ND	ND	0/9
Trichloroethene	µg/L	5	ND	ND	0/9	0.2	0.2	2/9	ND	ND	0/9
Xylene (total)	µg/L	10,000	ND	ND	0/9	0.7	0.5	4/9	ND	ND	0/9
Inorganic Analytes											
Aluminum	µg/L	*50 to 200*	27.5	16.6	2/8	120	58.6	4/8	87.1	54.1	3/8
Arsenic	µg/L	50	1.5	1.3	7/7	1.5	1.3	7/7	1.5	1.2	6/7
Barium	µg/L	2,000	26.2	21.1	8/8	52.8	45.3	8/8	44.3	37.3	8/8
Cadmium	µg/L	5	0.65	0.4	4/6	0.33	0.1	4/6	0.5	0.3	4/6
Chromium	µg/L	100	12.1	9.4	5/8	19	11.7	8/8	12.2	9	5/8
Copper	µg/L	1,000	1.6	1.6	1/8	4.5	4.5	1/8	3	3	1/8
Iron	µg/L	*300*	6,330	2,492	7/7	78.6	43.8	5/7	357	129.5	7/7
Lead	µg/L	15[b]	**25.9**	7.7	6/7	6.4	2.7	4/7	**44.8**	**21.8**	7/7
Manganese	µg/L	*50*	23	17.9	8/8	24.1	11	8/8	2.8	1.8	3/8

Table 4-8. (continued).

	Units	MCL or SMCL[a]	CFA-MON-001			CFA-MON-002			CFA-MON-003		
			MDV	ADV	NTD	MDV	ADV	NTD	MDV	ADV	NTD
Nickel	μg/L	None	1.5	1.5	1/8	4.5	2.9	2/8	2	1.4	2/8
Selenium	μg/L	50	1.3	0.7	2/7	3.3	2.7	3/6	1.9	1.9	1/5
Vanadium	μg/L	None	6.7	3.6	2/8	5.5	3	2/8	5.6	3.1	2/8
Zinc	μg/L	*5,000*	743	542.1	8/8	89.2	61.4	8/8	1,420	873.9	8/8

a. The numbers in italics are for secondary maximum contaminant levels (SMCLs)

b. Tap water action level for lead is 15 μg/L

ADV = Average Detected Value MDV = Maximum Detected Value ND = Not Detected TD = Number of Times Detected
Concentration in bold is above the MCL or action level for that analyte.

The distinct chemical grouping of the wells reflects the disposal of salty water at INTEC. Sodium and chloride have been disposed of in large quantities at INTEC for many years, and the USGS has been monitoring plumes of sodium and chloride in the groundwater (Robertson et al. 1974, Bartholomay et al. 1997). A discussion of the chloride and nitrate concentrations in the groundwater is presented below to illustrate the two distinct groundwater problems.

Chloride—Elevated chloride concentrations in groundwater are often used to detect and assess the impact of leachate from municipal or industrial landfills. The chloride ion is often used to delineate leachate in groundwater because it is often the primary anion in leachate, it is not affected by degradation processes, does not adsorb onto sediments, and it migrates with the groundwater. However, this approach to evaluating leachate impact is complicated by the fact that large volumes of wastewater containing sodium chloride, as well as other chemicals, have been discharged from the upgradient INTEC facility since 1953 (Bartholomay et al. 1997, Frederick and Behymer 1999). A chloride plume extends from INTEC to the CFA. The size and shape of the chloride plume has varied over time depending on the chloride concentration in the wastewater and the volume discharged, but it has been consistently present at CFA since the 1970s (Bartholomay et al. 1997, Frederick and Behymer 1999).

An isoconcentration map of chloride concentrations at CFA and INTEC was developed to evaluate the most current plume configuration (Figure C-26). The map is based on the most recently available data from CFA and INTEC wells (April or July of 1998). Based on the map, the source of chloride in the shallow landfill monitoring wells appears to be INTEC.

Well USGS 85, the upgradient well at Landfill III, is on the edge of the plume and shows only slightly elevated levels of chloride relative to the Landfill III downgradient wells. The INTEC plume may not be as deep as the pump intake for USGS 85 or USGS 85 may not be on the same flow path as the downgradient wells. Consequently, USGS 85 is not a good choice as an upgradient well for Landfill III.

The two eastern facility monitoring wells are near the leading edge of the plume and appear to be slightly impacted by the plume. CFA-MON-001 contains chloride concentrations essentially at background and does not appear to be impacted by the INTEC plume.

Nitrate—Nitrate concentrations range between 3 and 4 mg-N/L (milligrams of nitrate as nitrogen per liter) for the shallow landfill monitoring wells (Table 4-9). The lowest nitrate concentrations are found at the westernmost facility monitoring well and the two deeper wells. Nitrate was detected in concentrations above its MCL (10 mg/L) in CFA-MON-002 and CFA-MON-003. Nitrate was detected above the MCL in CFA-MON-003 in the first round of samples and has been measured above the MCL in approximately half of the samples. The average concentration of nitrate in CFA-MON-003 is 9.4 mg/L. Similarly, nitrate was consistently detected in concentrations above the MCL in CFA-MON-002. The nitrate data for CFA-MON-002 indicate a decreasing trend in concentration from the peak on April 1997 (20.5 mg/L) to the sample taken in April 1998 (16.3 mg/L). Nitrate concentrations in CFA Landfill wells upgradient from CFA-MON-002 and –003 have lower nitrate concentrations than the CFA-MON wells. In contrast, chloride concentrations are higher in wells upgradient from the CFA-MON wells indicating separate sources for the nitrate and chloride.

Trend analysis of the nitrate data from CFA-MON-A-002 and CFA-MON-A-003 was performed to determine if statistically significant trends were evident in the data sets. Analysis of the nitrate trend at CFA-MON-002 indicates a downward trend in concentration over time. A linear regression line through the CFA-MON-A-002 data yielded a slope of -0.0023 (Figure C-27) and a P-value of 0.0045, which indicates the downward trend is highly statistically significant. The linear regression line at CFA-MON-A-003 does not have a statistically significant slope and should not be extrapolated until additional data are collected (Figure C-28). The nitrate trends for both wells will be reevaluated after more data are collected.

Figure C-29 illustrates the concentration of nitrates in the CFA area. The map is based on data collected during the fourth quarter of 1996 because there are more data from surrounding wells in that quarter. The data utilized for the map are listed in Table 4-9. The source of the nitrate will be addressed further in an EDF. The EDF will include an evaluation of nitrogen isotope data from the wells in the CFA area.

4.3.2.2 Organic Analytical Results. Tables 4-6 through 4-8 present a summary of the organic data obtained for the 11 monitoring wells. No organic compound was detected above an MCL.

1,1,1-Trichloroethane (1,1,1-TCA) was detected in all the CFA monitoring wells, except CFA-MON-001, at concentrations between 0.1 and 0.4 µg/L. The contract required quantitation limit for 1,1,1-TCA is 1µg/L. All of the 1,1,1-TCA detections occurred in the first two rounds and the last round sampling events in both upgradient and downgradient wells from the CFA Landfills (Figures C-30 and C-31). The MCL for 1,1,1-TCA is 200 µg/L. The occurrence of 1,1,1-TCA in both upgradient and downgradient wells in the same sampling events suggests that the 1,1,1-TCA is either a sampling or laboratory artifact.

Toluene has been detected in well LF2-09 in eight of the nine samples at an average concentration of 5.2 µg/L. It was detected in much lower concentrations (between 0.7 and 1.1 µg/L) in LF2-11 and LF2-08 and has not been detected in LF2-10. The MCL for toluene is 1,000 µg/L.

The only well with consistent detections of organic compounds is CFA-MON-002. 1,2,4-Trimethylbenzene (1,2,4-TMB) and 1,3,5-trimethylbenzene (1,3,5-TMB) have been detected in every sampling round at average concentrations of 5.1 and 3.1 µg/L, respectively. No MCLs have been established for 1,2,4-TMB or 1,3,5-TMB. Very low concentrations of seven other organic compounds have been sporadically detected at CFA-MON-002 (Table 4-8), none of which are above their respective MCLs. No organic compounds were detected in CFA-MON-001 and CFA-MON-003 reported 1,1,1-TCA in only one of the sampling rounds.

Table 4-9. Nitrate groundwater results for the CFA area for the fourth quarter of 1996.

Well	Concentration mg/L as N	Date
CFA-1	3.6	10/16/96
CFA-MON-A-001	1.76	10/18/96
CFA-MON-A-002	18.8	10/17/96
CFA-MON-A-003	9.52	10/17/96
LF2-08	4.34	10/17/96
LF2-09	3.61	10/17/96
LF2-11	3.68	10/17/96
LF3-08	3.79	10/18/96
LF3-10	2.71	10/18/96
USGS-035	1.1	10/23/96
USGS-036	2	10/23/96
USGS-039	0.96	10/23/96
USGS-047	5.1	10/21/96
USGS-048	5.2	10/21/96
USGS-052	4.5	10/17/96
USGS-057	2.8	10/18/96
USGS-067	3.1	10/9/96
USGS-077	4.3	10/17/96
USGS-082	0.55	10/2/96
USGS-083	0.63	10/2/96
USGS-085	1.8	10/21/96
USGS-111	2.5	10/17/96
USGS-112	3.1	10/21/96
USGS-113	2.5	10/18/96
USGS-114	4.1	10/15/96
USGS-115	1.3	10/21/96
USGS-116	3	10/15/96

4.3.2.3 Inorganic Analytical Results. A few inorganic analytes exceeded MCLs or secondary maximum contaminant levels (SMCLs) and are described in the following sections. SMCLs are non-enforceable levels established for aesthetic reasons such as taste, odor or color, and are not health-based. The data are summarized in Tables 4-6 through 4-8. The complete list of sample analysis results are included in Appendix D.

Aluminum—A concentration range of 50 to 200 μg/L has been set as an SMCL. None of the samples collected during post-ROD monitoring exceeded the upper limit of the SMCL; however, several samples exceeded the minimum secondary standard of 50 μg/L. Background data for aluminum are not available.

Beryllium—Beryllium was listed as a COC in the monitoring work plan for Landfill II. Beryllium was not detected in any of the wells in the CFA monitoring network.

Cadmium—Cadmium was detected only once above its MCL of 5 µg/L. LF2-09 reported a concentration of 7 µg/L in July 1997; all other detections ranged between 0.06 and 0.3 µg/L. There are no qualifier flags associated with the reported cadmium level; however, given the very low concentrations in the other detections the 7 µg/L value is likely not valid.

Iron—Average iron concentrations exceeded the SMCL of 300 ug/L in four of the 11 wells. The average iron concentrations that exceed the SMCL are: 342 ug/L at LF3-10; 2,179 at LF2-11; 2,492 CFA-MON-001; 8,864 at LF2-09. The average concentration reported for LF2-09 is biased high because of a reported concentration of 54,600 ug/L in one sample. This concentration is likely attributable to an external source such as to the degradation of the steel well-construction materials or interbed material in the groundwater sample.

The concentration of iron in well CFA-MON-A-001 starts with a "no detect" on the first round of samples collected on 7/11/96 and increases to a maximum concentration of 6,330 µg/L on October 13, 1997 and then falls to 2,750 µg/L over the next 6 months (Figure C-32). The elevated iron levels in water at CFA-MON-001 may be due to the presence of interbed material in the groundwater at this location is a dark orange-red in color. It is possible that this interbed is present locally near the other locations thereby causing the elevated iron levels.

Additionally, field sampling logs indicate that all 11 CFA monitoring wells have high dissolved oxygen levels and a near neutral pH, suggesting that iron is not being transported in solution by the aquifer.

Lead—The State of Idaho groundwater quality standard and EPA tap water action level for lead is 15 µg/L. The action level was developed to monitor lead contributions from piping for public drinking water systems. If more than 10% of tap water samples exceed the action level, suppliers must implement corrosion control, increased monitoring and public education. The INEEL background concentration for lead is between 1 and 5 µg/L.

Only one of the landfill well samples was above the action level standard (LF 2-09 at 30.2 µg/L on July 1996). The average lead concentration at LF 2-09 was 7.7 µg/L.

One other well, CFA-MON-003, had an average lead concentration of 21.8 µg/L, which exceeds the State of Idaho groundwater standard of 15 µg/L. The lead concentrations in well CFA-MON-003 were above 15 µg/L in 5 of 7 samples. The lead concentrations peaked at 44.8 µg/L in July 1997 and then decreased to 19.7 µg/L by April 1998 (Figure C-32). The source of the lead in this well is not known; however, zinc and iron concentrations at this well followed the same trend as the lead and the occurrence of both metals together suggests a common source. Because the well casing has been found to be corroded, the source of the lead and zinc may be the galvanized well casing.

Manganese—One sample collected from LF 2-09 in July 1996, contained manganese (170 µg/L) at a concentration greater than the SMCL (50 µg/L). The other detected concentrations at this location ranged from 1.2 to 10.6 µg/L. The average manganese concentrations from all samples collected at the 11 wells were below the SMCL of 50 µg/L. The wells will continue to be monitored to determine if the one high sample was an isolated occurrence.

Mercury—The MCL for mercury is 2 µg/L. Mercury was reported in only 2 of 11 monitoring wells. Mercury concentrations of 0.7 and 3.7 µg/L were reported for a sample and a duplicate sample collected from LF3-08 in July 1997. The duplicate sample from LF 3-08 collected on July 8, 1997 contained mercury (3.7 µg/L). The data were flagged with an N and J, which means that the spiked sample recovery was above control limits and the values are estimated. Mercury was not detected in the other seven samples collected from LF3-08, indicating that the July 1997 data are likely not representative of aquifer conditions.

Zinc—Zinc concentrations do not exceed the SMCL of 5000 µg/L. Average zinc concentrations range between 6.5 µg/L at USGS-85 and 874 µg/L at CFA-MON-003 (Tables 4-6 through 4-8). Average concentrations for nine of the 11 monitoring wells exceed the Idaho State median background concentrations of 14.5 µg/L, although local CFA background concentrations may actually be higher due to influence from the INTEC plume.

4.3.2.4 Evaluation of the need for an additional Monitoring Well South of Landfill I.

The OU 4-12 Work Plan (Section 5.3) states the following:

"At this time, no additions to the existing groundwater monitoring system are planned, although the possible advantages of adding another groundwater monitoring well downgradient from Landfill I have been evaluated. All parties agreed, however, to increasing the level of vadose zone monitoring through the installation of additional soil gas sampling boreholes rather than installing the downgradient monitoring well. The need for additional monitoring well(s) will be reevaluated should future vadose zone or groundwater monitoring indicate that contaminants are leaching from the landfills."

As summarized in the previous section and in Figure C-30 and C-31, groundwater data show no evidence of landfill impacts. Appendix E contains an evaluation of the vadose zone data, as well as a summary of waste disposal history for Landfill I. These evaluations indicate that the vapor concentrations in the vapor monitoring wells are not high enough to pose a risk to groundwater.

Additionally, as Appendix E demonstrates, the only part of Landfill I that could potentially pose a risk to groundwater is the Western Waste Trench, which is actually beneath the Landfill III cover. Monitoring well LF3-08 will intercept potential contamination from the Western Waste Trench.

4.3.2.5 Groundwater Summary. In summary, no organic constituents in the CFA monitoring network exceed the MCLs for organic compounds. These data are intended to represent the baseline data set against which future analytical results will be compared. Mercury and cadmium were reported at concentrations slightly above their MCLs in single samples from different wells. Average lead and nitrate concentrations exceed their regulatory limits in two different wells.

The average lead concentration in CFA-MON-003 was during 1996 through 1998 21.8 µg/L, which is above the tap water action level of 15 µg/L. However, the concentrations are decreasing and the source of the lead appears to be a localized phenomenon. Background lead levels are between 1 and 5 µg/L for the INEEL.

Nitrate concentrations average 17 mg-N/L in CFA-MON-002 and 9.4 mg-N/L in CFA-MON-003. Trend analysis indicates that nitrate concentrations are declining in CFA-MON-002. The MCL for nitrate is 10 mg-N/L. Background nitrate concentrations range between 1 and 2 mg-N/L; upgradient nitrate levels at INTEC are between 1 and 5 mg-N/L. The source of the nitrate will be further evaluated in an EDF.

5. CONCLUSIONS

This section summarizes the results for the vadose zone monitoring and groundwater monitoring and draws conclusions on the effectiveness of the cover construction and performance and identifies the need for improvements.

5.1 Cover Effectiveness—TDR and NAT Data Analyses

Monitoring of the CFA landfills was conducted to determine whether annual precipitation infiltrated through the native soil covers and percolated through the buried waste, picking up contamination and carrying the contamination into the aquifer. Monitoring also was conducted to determine the production and/or migration of contaminated soil gases. In the monitoring plan (Neher 1997) for the CFA landfills, a performance criterion was to be set following the 2-year intensive monitoring phase. The TDR and neutron probe data methods indicate that all or most of the recharge occurs in April and May and coincides with the spring snow melt event. The NAT data indicates that the Landfill III cover is reducing the amount of infiltration.

Visual observations were used to assess the effectiveness of the design and construction of the cover. The post-ROD monitoring has been in progress for approximately 2 years. The visual observations of the cover indicate that no appreciable subsidence has occurred. Erosion of the covers appears to be minimal based on the lack of splaying of soil from runoff rivulets on the edges of the landfills. The landfill covers will be surveyed as part of the operation and maintenance plan. The covers have a good growth of vegetation that minimizes runoff. The conclusion from the observation is that the cover should reach its 30-year life expectancy.

Neutron probe data suggest that recharge is probably sporadic and depends not only on the amount of precipitation that falls in the winter, but also on the accumulation of snow and the suddenness of the snow melt. Estimates of recharge in 1998 ranged from 0.1 in. for LF3-05 to 2.57 inches for LF2-04. Recharge in 1998 was estimated using a water balance method and using calibration equations, but both methods yielded similar results. In contrast, recharge in 1997 was much less and ranged from not detectable to 2.62 cm (1.03 in.) at LF3-03.

Drainage calculations show that drainage occurred below the ET zone at all the NAT locations. Even though no recharge was indicated for LF3-05, drainage occurred, but the drainage reflected loss of water from storage rather than infiltration. Other NATs show that drainage below the ET zone and recharge are similar. The decrease of water in storage in the soil below the landfills suggests that the covers are reducing the amount of recharge at Landfill III and maybe at Landfill II.

The TDR data indicated that water moved through the 0.6-m (2-ft) cover, but the data does not indicate how much of this infiltration made it past the ET zone. A comparison of the neutron probe estimates with the TDR data at a depth of 0.6 m (2 ft) showed that the neutron probe measurements were at the low end of the range given by the TDR data.

Setting a performance criterion or action level to determine the effectiveness of the cover is complicated by the inconsistent and greatly varying recharge amounts. Recharge may vary considerable from one year to the next or recharge may be low for several years and then spike up in response to favorable weather conditions.

The strategy for achieving the stated project objective of establishing an action level for infiltration through the landfill cover is to collect three more years of data and reassess the situation to address this issue. Setting an action level based on impact on groundwater requires making assumptions as to the source size, concentration, compounds that might be present, and the amount of time that a source has been leaking. Because of the uncertainties associated with the above assumptions, establishing an action level for infiltration through the covers based on impact to groundwater would have considerable uncertainty.

5.2 Soil Gas Monitoring

Soil gases were collected and analyzed at four discrete depths from approximately 3.3 m (11 ft) to approximately 31.6 m (104 ft) below land surface at five locations adjacent to the landfills. Although the VOC data are variable and no clear trends are apparent, the following observations can be made. Of the 18 VOCs evaluated in the gas sampling, the following seven VOCs were reported most frequently and at the highest levels: 1,1,1-trichloroethane, 1,1-dichloroethane, 1,1-dichloroethene, methane, trichloroethene, dichlorodifluoromethane and trichlorofluoromethane. 1,1-Dichloroethane and 1,1-dichloroethene are most likely degradation products of 1,1,1-trichloroethane and methane is a common product of the anaerobic degradation of landfill wastes.

Boreholes GSP 3-1, GSP 1-1 and GSP 2-1 reported the highest concentrations of gas-phase VOCs, while GSP 3-2 and GSP 2-1 showed the lowest levels. The highest gas-phase VOC concentrations in the individual boreholes were detected with essentially equal frequency at the two intermediate sampling ports approximately 12.2 m (40 ft) and 21.3 m (70 ft) below grade. With only a few exceptions, concentrations decreased at the last sampling depth for all VOCs in all five boreholes.

The soil gas ports were installed adjacent to known fracture zones in the basalt. The organic vapors, primarily chlorinated solvents, are probably migrating through preferential vertical and horizontal flow paths in the fractured basalt. Based on levels of VOCs in the vadose zone at RWMC and the resultant impact on groundwater, it is unlikely that the observed concentrations at the CFA landfills will impact the SRPA above MCLs.

Given the age of the landfills, it is possible that vadoze zone gas concentrations were higher in the past and that the majority of contaminants may have migrated away from the landfill. However, this does not mean that soil gas concentrations are greater at depths below the deepest gas sampling port because contaminant concentrations in soil gas tend to decrease due to dilution, vertical and horizontal diffusion, and dispersion of vapors as they migrate over larger areas. One line of evidence against higher concentrations having migrated to depth is that the concentrations uniformly attenuate with depth in the GSPs.

5.3 Water-level Monitoring

Groundwater elevations determined during this monitoring activity appear to be questionable for some wells. The concerns about quality arise from the great depth to water and the very flat water table. The need for very accurate measurements at great depth amplify any sources of error introduced into water level measuring process.

The estimated total error associated with water-level measurements was determined to range from 0.09 to 0.3 m (0.3 to 1.0 ft) for the 27 wells included in this study. Errors as high as 0.3 m (1.0 ft) explain some of the apparent anomalies seen when hydrographs (water-level time series) of the various 27 wells are compared. However, some wells (such as USGS 20 and USGS 35) remain anomalous.

Hydrograph error bands ranging from 0.09 to 0.3 m (0.3 to 1.0 ft) can make interpretation of the local groundwater surface difficult. The water table contour plots based on these water levels may be misleading and predications of local flow gradients and directions may be inaccurate. Because of measurement uncertainties, the contour plot's accuracy is reduced to more of a regional-scale characterization of gradients and groundwater flow direction.

It is important to note that a chloride isoconcentration map generated for this report also shows a south-southwest groundwater flow direction in the vicinity of the landfills. Additionally, maps from the State of Idaho, INEEL Oversight Program for chloride show the same south-southwest flow direction around the landfills over the past 30 years.

5.4 Groundwater Monitoring

Groundwater samples were collected from eight monitoring wells surrounding the landfills and three wells downgradient of the CFA sewage treatment facility. Groundwater samples were collected and analyzed for the VOCs, metals and cations/anions.

No organic constituents in the CFA monitoring network exceed the MCLs for organic compounds. Mercury and cadmium were reported at concentrations slightly above their MCLs in single samples from different wells. Lead concentrations are elevated in one well; nitrate concentrations are elevated in two wells.

The average lead concentration in CFA-MON-003 during 1996 – 1998 was 21.8 μg/L, which is above the State of Idaho groundwater standard of 15 μg/L. However, the concentrations are decreasing and the source of the lead appears to be a localized phenomenon. Background lead levels in and around the INEEL ranged between 1 and 5 μg/L.

Nitrate concentrations average 17 mg-N/L in CFA-MON-002 and 9.4 mg-N/L in CFA-MON-003. Trend line analysis indicates that nitrate concentrations are declining in CFA-MON-002 whereas a downward trend can not be quantified in CFA-MON-003. The MCL for nitrate is 10 mg-N/L. Background nitrate concentrations range between 1 and 2 mg-N/L; upgradient nitrate levels at INTEC are between 1 and 5 mg-N/L. The source of the nitrate will be further evaluated in an EDF.

6. RECOMMENDATIONS

The following recommendations are made to address data gaps identified in the first 2 years of monitoring and focus monitoring efforts through 2003. After that time, recommendations will be made for long-term monitoring.

6.1 Cover Infiltration Monitoring

The following suggestions, if implemented, will provide more accurate infiltration and drainage estimates in the landfill area.

- Install two sets of vertical TDR probes to a depth of 2.4 m (8 ft) in Landfills II and III near the NAT tubes located on each landfill. TDR measurements will be used in UNSAT-H modeling to determine an infiltration and recharge rate. TDR monitoring should be included in the long-term monitoring plan to determine if this automated system gives the same infiltration rate estimates as the neutron probe measurements.

- The HELP model should not be used to evaluate infiltration or recharge rates for the landfills because this model is not applicable to arid regions. UNSAT-H is a model that can better be used to determine infiltration and recharge rates in arid climate settings.

- Measure the total depth and casing stick-ups of the NATs. This will improve the accuracy of the depths assigned to the neutron moisture probe stops.

- Increase frequency of NAT monitoring in late winter and early spring. The following schedule of NAT monitoring is suggested: twice a month in January and February, March, and April, and once a month during the rest of the year. The frequency of monitoring may be increased during periods of increased precipitation.

6.2 Soil Gas Monitoring

- Sampling should continue twice a year through 2003 to identify any trends.

- Modeling should be conducted after collecting additional soil gas data to determine if detected contaminants pose a risk to groundwater above MCLs.

- The work plan states that an action level for VOCs in the vadoze zone would be established in this report. However, as has been discussed with the agencies, it is unclear that a meaningful action level for vadoze zone vapors can be established. This decision will be deferred until additional data are collected.

6.3 Groundwater Monitoring

The long-term groundwater monitoring schedule will be determined after collecting additional data through 2003.

6.3.1 Water-level Monitoring

- The groundwater flow direction will be reassessed after water-level measurements have been taken on a monthly basis for 1 year with a steel tape.

- The following wells should be resurveyed with gyroscopic deviation equipment but at intervals of 7.5 m (25 ft): USGS-20, USGS-111, USGS-116, CFA-MON-A-001, CFA-MON-A-002, and CFA-MON-A-003. Information from the resurveyed wells should be used to recalculate the correction formula used to obtain true water levels in these highly deviated wells.

6.3.2 Groundwater Sampling

- Groundwater sampling should continue on a schedule of no less than every 12 months. The only constituent of concern at the CFA is nitrate and it is not fluctuating enough to warrant more frequent monitoring.

- LF 2-10, LF 2-08, and LF 3-09 should be removed from the list of routine sampling. The screened interval at LF 2-10 is too deep to evaluate the impact of landfill leachate. LF 2-08 and LF 3-09 are located very near other wells that have the same screened interval.

- USGS-83 should be added to the list of wells to be sampled because this well is downgradient of the nitrate contamination in the CFA-MON wells. The pump in USGS-83 should be raised to sample near the top of the water table.

- USGS-85 should not be designated as the upgradient well for Landfills I and III. USGS-112 would serve better as the upgradient well for Landfills I and III because this well is in the upgradient flow path of the landfill wells whereas USGS-85 is not.

6.4 Changes to Work Plan

The Post-ROD Monitoring Work Plan (Neher 1997) specified that action levels would be set for VOCs in vadose zone gas and for landfill infiltration monitoring. The efficacy of setting action levels when no source term has been identified may be questionable. Action levels will be discussed after additional data have been collected.

The monitoring frequency of the NATs and TDRs needs to be modified to once a month in the period from May to December and at least twice a month in January thorough March. The frequency may need to be once a week in the February-March time frame if a sudden snow melt event occurs. These changes will be documented in a Document Action Request for the Post-ROD Monitoring Work Plan.

7. REFERENCES

54 FR 48184, 40 CFR 300, July 1997, "National Priorities List of Superfund Sites," *Code of Federal Regulations,* Final Rule, U.S. Government Printing Office.

Ackerman, D. J., 1991,"Transmissivity of the Snake River Plain Aquifer at the Idaho National Engineering Laboratory, Idaho," *U.S. Geological Survey Water-Resources Investigations Report* 91-4058.

Anderson, et al., 1987, "Control of the Soil Water Balance by Sagebrush and Three Perennial Grasses in a Cold-Desert Environment," *Arid Soil Research and Rehabilitation, 1*, pp. 229–244.

Ansley, S. L., L. C. Hull, and S. M. Burns, 1988, *Shallow Drilling Report for CFA Landfills II and III - FY-1988, Characterization of Surficial Sediments,* EGG-ER 8291, Rev. 1.

Armstong, R. L., W. P. Leeman, and H. E. Malde, 1975, "K-Ar Dating, Quaternary and Neogene Rocks of the Snake River Plain, Idaho," *American Journal of Science*, pp. 225–251.

Barraclough, J. R., J. B. Robertson, and V. J. Janzer, 1976, "Hydrology of the Solid Waste Burial Ground, as Related to the Potential Migration of Radionuclides," *U.S. Geological Survey Open-File Repot 76-471.*

Barthlomay R. C., 1990, *Mineralogical Correlation of Surficial Sediment from Area Drainages, with Selected Sedimentary Interbeds at the Idaho National Engineering Laboratory, Idaho*, U.S. Geological Survey Water Resources Investigations Report 90-4147, August.

Bartholomay, R. C., B. J. Tucker, D. J. Ackerman, and M. J. Liszewski, 1997, *Hydrologic Conditions and Distribution of Selected Radiochemical and Chemical Constituents in Water, Snake River Plain Aquifer, Idaho National Engineering Laboratory, Idaho, 1992 Through 1995*, DOE/ID-22137, U.S. Geological Survey, Idaho Falls, ID.

Beard, K. V., 1998, Personal communication and data transmittal, October.

Blackmore, C., R. Peatross, and I. Stephan, 1996, *Preliminary Scoping Track 2 Summary Report for Operable Unit 4-05,* INEL-95/0626, Rev. 0.

Boulding, J. R., *Practical Handbook of Soil, Vadose Zone, and Ground-Water Contamination Assessment, Prevention, and Remediation*, CRC Press, 1995.

Burgess, J., S. Flynn, P. Jessmore, J. Keck, S. McCormick, M. Rohe, I. Stepan, R. VanHorn, S. Fu, and L. Trozollo, 1998, *Comprehensive Remedial Investigation/Feasibility Study for the Central Facilities Area Operable Unit 4-13 at the Idaho National Engineering and Environmental Laboratory*, DOE/ID-10596, Rev. 0.

Clawson, K. L., B. E. Start, and N. R. Ricks, December 1989, Climatography of the Idaho National Engineering Laboratory, 2nd ed., DOE/ID-12118, Department Energy Idaho Operations.

Crockett, J. K., 1995, Idaho Statewide Groundwater Quality Monitoring Program – Summary of Results 1991–1993, Idaho Department of Water Resources, Information Bulletin #50 Part 2., April.

DOE-ID, 1991, *Federal Facility Agreement and Consent Order for the Idaho National Engineering Laboratory,* 1088-06-29-120, U.S. Department of Energy, Idaho Field Office, U.S. Environmental Protection Agency, Region 10; State of Idaho, Department of Health and Welfare, December.

DOE-ID, 1994, *Idaho National Engineering Laboratory Comprehensive Well Survey*, DOE-10402, September 1994.

DOE-ID, Environmental Protection Agency, and Idaho Department of Health and Welfare, October 10, 1995, *Record of Decision: Declaration for Central Facilities Area Landfills I, II, and III (Operable Unit 4-12), and No Action Sites*, Idaho Falls, Idaho.

DOE-ID, 1997a, *Final Work Plan for Waste Area Group 4 Operable Unit 4-13 Comprehensive Remedial Investigation/Feasibility Study*, DOE/ID-10550, March.

DOE-ID, 1997b, *Quality Assurance Project Plan for Waste Area Groups 1, 2, 3, 4, 5, 6, 7, 10, and Inactive Sites,* DOE/ID-10587, Revision 5, December.

DOE-ID, 1997c, *Comprehensive RI/FS for the Idaho Chemical Processing Plant OU 3-13 at the INEEL—Part B, FS Report (Final),* U.S. Department of Energy Idaho Operations Office, DOE/ID-10572, November.

Hackett, B., J. Pelton, and C. Brockway, 1986, "Geohydrologic Story of the Eastern Snake River Plain and the Idaho National Engineering Laboratory," DOE/ID, November.

INEEL, 1998a, Barriers Test Facility, FY-1997 and FY-1998, INEEL EXR-98-00964.

INEEL, 1998b, *1997 LMITCO Environmental Monitoring Program Report for the Idaho National Engineering and Environmental Laboratory*, INEEL/EXT-98-00305, Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID.

Keck, K.N., Porro, I., Sondrup, A.J., McCormick, S.H., Lewis, S.M., 1995, *Remedial Investigation/Feasibility Study for Operable Unit 4-12: Central Facilities Area Landfills I, II, and III at the Idaho National Engineering Laboratory,* INEL-94/0124,.

Knobel, L.L., B.R. Orr, L.D. Cecil, 1992, "Summary of Concentrations of Selected Radiochemical and Chemical Constituents in Groundwater from the Snake River Plain Aquifer, Idaho: Estimated from an Analysis of Previously Published Data," *Journal of the Idaho Academy of Science*, Vol. 28, No. 1, June, pps. 48–61.

Knobel, L. L., R. C. Bartholomay, and B. R. Orr, 1997, *Preliminary Delineation of Natural Geochemical Reactions, Snake River Plain Aquifer System, Idaho National Engineering Laboratory and Vicinity, Idaho*, DOE/ID-22139, U.S. Geological Survey Water-Resource Investigations Report 91-4015, Idaho Falls, ID.

Kramer, J. H., S. J. Cullen, and L. G. Everett, 1992, *Vadose zone monitoring with the neutron probe.* Ground Water Monitoring and Remediation. V. 12, no. 3, 177–187.

Ledieu, et al., 1986, J., De Ridder, P., De Clerck, P., and Dautrebande, S., *A Method of Measuring Soil Moisture by Time-domain Reflectometry*, Journal of Hydrology, 88, pg. 319-328.

Lewis, B. D. and F. J. Goldstein, 1982, *Evaluation of a Predictive Ground-Water Solute-Transport-Model at the Idaho National Engineering Laboratory*, IDO-22062, U.S. Geological Survey Water-Resources Investigation 82-25.

Lewis, B. D. and R. G. Jensen, 1984, *Hydrologic Conditions at the Idaho National Engineering Laboratory, Idaho, 1979–1981 Update*, U.S. Geological Survey Open-File Report 84-230, IDO-2066.

Mann, L. J. and L. D. Cecil, 1990, "Tritium in Ground Water at the Idaho National Engineering Laboratory, Idaho ," *U.S. Geological Survey Water Resources Investigations Report 90-40901*, DOE/ID-22075, Idaho Falls, ID.

Mann, L. J and L. L. Knobel, 1988, "Concentrations of Nine Trace Metals in Ground Water at the Idaho National Engineering Laboratory, Idaho," *U.S. Geological Survey Open-File Report 88-332*, DOE/ID-22075, Idaho Falls, ID.

Miller, S.M., J.E. Hammel, and L.F. Hall, 1990, *Characterization of Soil Cover and Estimation of Water Infiltration at Central Facilities Area Landfill II,* Idaho National Engineering Laboratory, Idaho Falls, ID.

Mundorff, M. J., E. G. Crosthwaite, and C. Kilburn, 1964, *Ground Water for Irrigation in the Snake River Basin in Idaho*, U.S. Geological Survey, Water Supply Paper 1654.

Nace, R. L., M. Deutsch, and P. T. Voegeli, 1956, *Geography, Geology, and Water Resources of the National Reactor Testing Station, Idaho: Part 2, Geography, and Geology*, IDO-22033, U.S. Geological Survey, Boise, ID.

Nace, R. L., J. W. Stewart, W. C. Walton, et al., 1959, *Geography, Geology, and Water Resources of the National Reactor Testing Station, Idaho*, Part 3, Hydrology and Water Resources, IDO-22034-USGS.

Neher, Erick, 1997, *Post Record of Decision Monitoring Work Plan Central Facilities Area*, Landfills I, II, and III, Operable Unit 4-12, INEL-95/0579.

Nicklaus, D., S. Francis, C. Reese, J. Sherwood, and H. Salomon, 1998, *Removal Action Summary of CFA-04 Pond and TSF-08 Time Critical Removal Actions*, INEL-95/0382, Rev. 2.

Orr, B. R. and L. D. Cecil, 1991, "Hydrologic Conditions and Distribution of Selected Chemical Constituents in Water, Snake River Plain Aquifer, Idaho National Engineering Laboratory, Idaho 1986 to 1988," *U.S. Geological Survey-Water Resources Investigations Report 91-4047*, DOE/ID-22096.

Orr, B. R., L. D. Cecil, and L. L. Knobel, 1991, *Background Concentrations of Selected Radionuclides, Organic Compounds, and Chemical Constituents in Ground Water in the Vicinity of the Idaho National Engineering Laboratory*, DOE/ID-22094, U. S. Geological Survey, Idaho Falls, ID.

Pierce, K. L., and L. A. Morgan, 1992, "Track of the Yellowstone Hotspot: Volcanism, Faulting, and Uplift," *Geological Society of America Memoir 179*, pp. 1□53.

Pittman, J. R., R. G. Jensen, and P. R. Fisher, *Hydrologic Conditions at the Idaho National Engineering Laboratory, 1982 – 1985,* U.S.G.S. Water Resources Investigation Report, 89-4008, DOE/ID-22078.

Porro, I. and K. N. Keck, 1998, "Engineered Barrier Testing at the INEEL Engineered Test Facility".

Rightmire, C. T., 1984, "Description and Hydrologic Implications of Cored Sedimentary Material from the 1975 Drilling Program at the Radioactive Waste Management Complex, Idaho," *U.S. Geological Survey Open-File Report 84-4071.*

Robertson, J. B., R. Schoen, and J. T. Barraclough, 1974, *The Influence of Liquid Waste Disposal on the Geochemistry of Water at the National Reactor Testing Station, Idaho: 1952-1970,* IDO-22053, U.S. Geological Survey, Idaho Falls, ID.

Rothermel, J. S., G. B. Cotton, 1996, *Remedial Design/Remedial Action Work Plan, Central Facilities Area Landfills I, II, and III, Native Soil Cover Project,* INEL-95/0638, Rev. 2

Sagendorf, J., 1991 *Meteorological Information for RWMC Flood Potential Studies,* U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Research Laboratories, Air Resources Laboratory Field Research Division, Idaho Falls, Idaho.

Scott, W. E. 1982, "Surficial Geologic Map of the Eastern Snake River Plain and Adjacent Areas, Idaho and Wyoming, "U.S. Geological Survey Miscellaneous Investigation Map I-1372.

Sorenson, K. S. Jr., 1996, *Hydraulic Evaluation of Landfill Performance Model Analysis and Optimization of Central Facilities Area Landfills Cover Design Criteria Operable Unit 4-12,* INEL-95/0543.

Stephens, D. B., and Associates, Inc., 1993, *Laboratory Analysis of Soil Hydraulic Properties of Central Facilities Area Landfills II and III,* Albuquerque, NM.

Van Deusen, L., and R. Trout, 1990, *Draft, Phase I Remedial Investigation/Feasibility Study Work Plan and Addendum for the Warm Waste Pond Operable Unit at the Test Reactor Area of the Idaho National Engineering Laboratory (Volumes I and II),* EGG-WM-8814, July.

Wells, R. P., 1996, *Field Sampling Plan for the Post Record of Decision Monitoring, Central Facilities Area Landfills I, II, and III, Operable Unit 4-12,* INEL/95-0585, June.

Whalley, W.R., 1993, Considerations on the Use of Time-Domain Reflectometry (TDR) for Measuring Soil Water Content, Journal of Soil Science, 1993, 44, 1-9.

Whitehead, R. L., 1986, "Geohydrologic Framework of the Snake River Plain, Idaho and Western Oregon," U.S. Geological Survey Atlas, HA-681.

Wood, T. R., 1989, *Test Area North Pumping Tests*, EGG-ER-8438, January

Wood, T. R., L. C. Hull, and M. H. Doornbos, 1989, *Groundwater Monitoring Plan and Interim Status Report for Central Facilities Landfill II*, EGG-ER-8496, April.

Wylie, A. H., 1993, *Gyroscopic Directional Survey of Central Facilities Area Ground Water Wells, Parts I and II*, ER-WAG4-31 and ER-WAG4-32, July.